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ON

THE USE OF LIME

IN

AGRICULTURE.

BY

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INTRODUCTION.

THE proper use of lime is, in our climate, of so much importance to the practical farmer who wishes to make his land at once fertile and profitable, that I believe I am rendering a service to economical agriculture by publishing in a separate form the numerous observations and deductions which have occurred to me during the seven years that my attention has been drawn to this subject. I cannot pretend to have cleared up every thing in connection with the use of this valuable fertilizing agent, but I have been able to introduce as much true and plain matter as will, I think, well re-pay any young farmer who may devote a couple of weeks to the perusal of this little work.

I have discussed, first, the use of lime in its mild state of carbonate of lime, and in its caustic state of burned lime; and have then devoted two chapters to the sulphate of lime (gypsum), and to the phosphate of lime (bone-earth)—two substances which are of great value and of extensive use, and the theory of the action of which, as well as the proper mode of using them, it is of much consequence to understand. By these additions the work is rendered more complete.

Durham, January, 1849.

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CHAPTER I.

Use of lime as an application to the soil. Natural forms in which lime is applied to the land. States of chemical combination in which lime occurs in nature and is applied to the land. Carbonate, sulphate, phosphate, silicate, and nitrate of lime. Different varieties of marl. Composition of marls. Origin of marl beds. Shell, coral, and infusorial sands. Limestone sand and gravel and crushed limestone. Use of chalk.

The use of lime as an application to the soil is of high antiquity, and its utility has been recognised in almost every country in which agriculture has attained to any degree of perfection. In our country it has been called *the basis of all good husbandry*—and it certainly is more largely and more extensively used than any other mineral substance which has ever been made available in practical husbandry. I hope, therefore, I shall be rendering a service to agriculture by bringing together in the following little work the greater part of what we as yet know, in regard to the practice and theory of the use of lime.

Lime is applied to the land in several states of chemical combination and in a great variety of forms, some of them natural and others artificially prepared. In the present chapter I shall describe the several chemical states and the more important of the natural and unprepared forms of marl, shell-sand, &c., in which lime is employed for fertilizing the soil.

SECTION I.—OF THE DIFFERENT STATES OF CHEMICAL COMBINATION IN WHICH LIME IS FOUND IN NATURE AND IS APPLIED TO THE LAND.

Lime is applied to the land in various states of chemical combination, the nature, composition, and properties of which it is necessary that the reader should, in the first place, in some measure understand. It is chiefly applied in the states of carbonate, sulphate, phosphate, and silicate.

1°. *Carbonate of lime* is the most abundant of these compounds, and that which is most generally employed in agriculture, but the meaning of this word *carbonate* it will be proper to explain.

Fig 1.

A. If a few pieces of limestone or chalk be put into the bottom of a beer glass (fig. 1) and diluted spirit of salt or strong vinegar be poured over them, a boiling up or effervescence will take place. This boiling up is caused by the production of a kind of air, to which the name of *carbonic acid* gas is given.

Fig. 2.

This air will extinguish a lighted taper introduced into it, and is so heavy that it may be poured from one vessel to another (figs. 1 and 2). It exists naturally in the limestone, and is driven out or separated from it by the vinegar or spirit of salt.

If this carbonic acid be prepared by putting the pieces of

Fig. 3.

limestone and the acid into a bottle, through the cork of which a bent tube is introduced, terminating at the other end in a glass of water (fig. 3), the gas will pass through the tube, will rise in bubbles, and will impregnate the water. Water dissolves and retains its own bulk of this gas at the ordinary pressure and temperature of the atmosphere. Soda water is impregnated with it, under strong pressure, and hence the violent effervescence which takes place when the cork of a soda water bottle is drawn.

This gas exists in small quantity in the atmosphere, and hence every shower of rain that falls dissolves a little of it out of the air and comes to the earth, impregnated to a certain extent with carbonic acid. This fact, as we shall afterwards find, is of considerable practical importance.

B. If a small piece of *quick* or burned lime be crushed to powder, put into a bottle full of water, well shaken up, and then allowed to settle, the water will become as clear as before, but will contain lime. It will be what is called *lime-water*.

If this clear and transparent lime-water be now poured into the beer glass, and the carbonic acid gas made to pass through it (fig. 3), the liquid will become milky, and if the glass be removed from the action of the gas a white powder will fall.

This white powder is produced by the combination of the *carbonic* acid gas with the lime contained in the water—and hence it is called *carbonate* of lime. It is

the same thing as pure finely powdered chalk or limestone, and is *insoluble in pure water*.

One hundred pounds of carbonate of lime contain about 44 lbs. of carbonic acid and 51 lbs of lime, *or one ton of pure carbonate of lime contains* 11¼ Cwt *~~tons~~ of lime.*

c. But if the lime-water, after it has become milky, is not removed from the action of the gas, but the bubbles are still allowed to pass through it, the milkiness will gradually disappear, and the liquid will become transparent as at first. The carbonate of lime at first formed will be dissolved—through the absorption of more carbonic acid, and the formation of what is called *bi*-carbonate of lime, which is soluble in water.

If this clear solution be poured into a wide-mouthed tumbler, a film will gradually form on its surface, and if it be stirred about or warmed it will become milky. The water will part with the second portion of carbonic acid which had been absorbed, and the insoluble carbonate of lime will again fall.

These facts are of practical importance, as showing

a. That carbonate of lime, though insoluble in pure water, is soluble to a certain extent in water impregnated with carbonic acid gas.

b. That when water, which holds lime in solution in this way, is exposed to the air for a length of time, or to heat, the lime will again separate from it more or less completely. It is in this way that stalactites are formed in caves, that drains are often choked up with lime, that substances are frequently petrified in lakes and running streams—that beds of marl in some cases are produced (p. 16), and that crusts are deposited at the bottoms of our kettles and steam boilers.

2°. *Sulphate of lime or gypsum.*—The common oil of vitriol of the shops is called *sulphuric acid* by chemists. If a drop of this sulphuric acid is mixed with lime water quite saturated with lime, it will render it slightly milky, and a white powder will fall. The white powder in this case is a combination of the sulphuric acid with the lime,

and is called *sulphate of lime*.* Under the name of gypsum, this sulphate of lime is well known to the farmer.

A hundred pounds of common gypsum consist of 46 lbs. of sulphuric acid, 33 lbs. of lime, and 21 lbs. of water. When it is heated to redness, this water is driven off, and the gypsum is then very easily reduced to an exceedingly fine powder. In this finely powdered state, it forms the plaster of Paris or common stucco, and is much employed for making plaster casts. When mixed with water to the thickness of cream, this fine powder speedily sets or becomes hard. This arises from its absorbing the water it had lost by heating and becoming again changed into common gypsum.

A hundred pounds of burned gypsum consist of 58½ lbs. of sulphuric acid and 41½ of lime. This weight absorbs 26¼ lbs. of water, and forms 126¼ lbs. of common gypsum.

Gypsum dissolves in 500 times its weight of pure water, or 50 gallons will dissolve one pound. Hence it often exists in spring water and in rain water, which has flowed through a soil in which gypsum exists or to which it has been added.

Gypsum in solution in water possesses the property of being decomposed when mixed with fermenting animal or vegetable matter. The water of the baths of Louesch are charged principally with gypsum. In these baths the patients remain immersed for six or eight hours a day, at a temperature of 80° or 90° F., and during this time the waters acquire a decidedly sulphureous character, though they shew no trace of it when they first issue from the spring. Inclosed in a bottle with animal or vegetable matter, a solution of gypsum becomes sulphureous. Hence sea-water, which contains gypsum,

* It is formed much more abundantly if a solution of chalk or limestone in spirit of salt be added to one of Epsom or of glauber salts in water. The white powder, which falls on mixing the solutions, is gypsum.

and abounds in minute animals, when kept for a time in a close vessel, becomes sulphureous. Mixed with the mud of the sea-shore, gypsum is also decomposed, and hence the sulphureous odour which the sea-breeze brings with it over low tracts of muddy land which are deserted by the sea when the tide retires. The unhealthy character of the African coasts has been ascribed by some to the prevalence of such sulphureous exhalations. It can scarcely, I think, be doubted that gypsum, if present in the centre of a hot fermenting dung heap, will undergo a similar decomposition.

Fig. 4.

3°. *Phosphate of lime.*—When a piece of phosphorus is kindled in the air or under a glass (fig. 4), it burns rapidly and gives off dense white fumes. These white fumes which will collect on the sides of the glass in the form of a fine white powder are *phosphoric acid.** This phosphoric acid unites with lime, and forms *phosphate* of lime.

Phosphate of lime is laid upon the land in two forms.

a. In that of *earth of bones.* When bones are burned in an open fire they leave a bulky white porous ash, which consists of a peculiar phosphate mixed with a little carbonate of lime. One hundred pounds of this phosphate consist of 48½ lbs. of phosphoric acid and 51½ of lime.

b. In that of *mineral phosphate* or apatite. This variety sometimes occurs in nature in veins and in considerable masses. In this form it is known to exist in Estremadura in Spain, but it is too remote from markets to be made available, at present, for agricultural purposes. In

* The same white fumes are formed when a common lucifer match, of the variety which kindles without explosion, is rubbed upon the sand paper. The match is tipped with a little phosphorus for the purpose of kindling the sulphur.

smaller quantities it exists in nearly all limestones and marls, and it is only in this state of mixture that the mineral phosphate has yet been applied extensively to the land. A hundred pounds of this mineral phosphate consist of 45½ lbs. of phosphoric acid and 54½ lbs. of lime.

Both of these phosphates are insoluble in water, but they dissolve readily in strong acids.*

4°. *Silicate of lime* is formed when sand and lime are melted together in a furnace. It exists in glass, in the slags of the iron smelting furnaces, and in various other substances rejected from our manufactories. It exists also in many of those rocks from which our soils are formed, and is one of the natural sources of fertility in those which are produced by the decay of the trap (whin-stone), and some other varieties of igneous or crystalline rocks.

5°. *Nitrate of lime.*—When common chalk or limestone is dissolved in nitric acid (aquafortis), nitrate of lime is obtained in the solution. This nitrate of lime is often produced naturally in compost heaps to which lime has been added, and it is only in such composts that it has hitherto been added in any quantity to the land.

The chemical composition of 100 lbs. of the several varieties of lime, above described, is represented in the following table :—

	Acid.	Lime.	Water.
Carbonate of lime consists of	43·7	56·3	——
Bi-carbonate of lime	60·8	39·2	——
Sulphate of lime *(gypsum)*	46·3	32·9	20·8
Sulphate of lime *(burned)*	58·5	41·5	——
Phosphate of lime *(of bones)*	48·5	51·5	——
Phosphate of lime *(mineral)*	45·5	54·5	——
Bi-phosphate of lime	71·5	28·5	——

I shall have occasion to allude to the last of these

* Such as the sulphuric *(oil of vitriol)*; the muriatic *(spirit of salt)*; and the nitric acid *(aquafortis)*.

substances, the *bi*-phosphate, in a succeeding chapter The silicate of lime varies in composition. One of the most common varieties contains 38 per cent. of lime.

SECTION II.—OF DIFFERENT VARIETIES OF MARL.

By the term *marl* is understood an earthy mixture containing generally not less than one-fifth part of its weight, or 20 per cent. of carbonate of lime. If the proportion of lime be less than this, the mixture is rather a marly clay or soil than a true marl. The presence of lime in a marl is shown by putting a little of it into a wine glass and pouring over it strong vinegar or diluted spirit of salt (muriatic acid), when, if lime be present, it will boil up or *effervesce* like brisk beer.

When a piece of a stiff or tenacious marl is put into water it loses its coherence and gradually falls to powder. This is a very simple way of distinguishing between a marl and a stiff clay. Though this test however affords a presumption that the substance is a marl, it does not shew the fact with certainty. It must still be tried with vinegar or some other acid.

Marls are of various kinds, differing in colour, in hardness, in dryness, and in the proportion of lime they contain.

1°. *Dry marls.*—The dryness of a marl is a point of considerable importance in an economical point of view, where it has to be carted to any considerable distance. Dry marls are also of various kinds.

a. Powdery marls.—These are generally the driest, the most easily spread, and the richest in lime.

b. Clay marls have the appearance of a more or less tenacious clay. If they contain much lime they fall to powder when put into a basin of water.

c. Stony marls are often richer in lime than those which are clayey. They are generally spread upon the

land in their stony state in the autumn, when they crumble and fall to pieces under the action of the winter's frost.

2°. *Wet marls.*—Some marls are not only very wet when they are dug up, but take a very long time to dry when they are laid in heaps in the open air. Among these are especially to be noticed the peaty marls which in many parts of our island are found in hollow places at the foot of our hills, and covered by a greater or less thickness of peat. These marls are mixed with a certain proportion of peaty matter which causes them to retain water with great obstinacy. Even after being exposed to the air for some months they not unfrequently retain still one-fourth or more of their weight of water. This adds greatly to the cost of transport, and often enables sea-borne lime to come into successful competition with native marls at a considerable distance from the coast. When brought to the farm, also, their wetness prevents them from being easily and equally spread upon the land. Hence they are usually formed into composts and laid on after a considerable lapse of time, or in the wet newly dug state they are mixed with five times their bulk of farm-yard manure. This latter mode is said greatly to improve the manure for the turnip crop.

These marls might be easily dried where peat abounds, by burning the two together in a kiln, which could be easily contrived, and which would require only a certain quantity of dried peat to set it agoing. Or when brought to the farm they may be mellowed, dried, and made to crumble down by being mixed with a certain quantity of lime shells. The shells will be slaked by the water in the marl, and the whole will fall to fine powder. Even where burned lime has to be brought from a considerable distance, and is, therefore, costly, it may be worth the farmer's while to buy a portion of it for the purpose of mixing with and reducing the marl which he can procure at a cheaper rate. The proportion of lime

he will require will depend upon the quantity of water which his marl contains.

SECTION III.—OF THE COMPOSITION OF MARLS.

All the kinds of marl above described vary very much in chemical composition.

1°. The following table shews how very much the *dry* marls, not only of different kinds but of similar kinds also, may differ from each other in the proportions of carbonate, sulphate, and phosphate of lime they severally contain:—

	COMPOSITION OF DRY MARLS.				
	Powdery.		Clayey.	Stony.	
	Luneburg.	Wesermarsh.	Magdeburg.	Osnabruck.	Brunswick.
Carbonate of lime	85·4	8·2	18·2	35·0	13·3
Carbonate of magnesia	1·3	3·0	3·8	0·9	2·6
Sulphate of lime	0·1	0·5	2·1	0·9	trace.
Phosphate of lime	2·3	1·2	0·5	0·5	1·2
Alumina	0·4	3·1	8·4	10·0	4·0
Oxides of iron & manganese	4·2	4·1	7·0	1·9	7·6
Sulphuret of iron	—	—	—	7·3	—
Common salt, potash, & soda	0·1	1·0	1·6	trace.	0·2
Quartz sand and silica	5·6	78·9	58·4	23·0	71·1
Organic matter	0·6	—	—	20·5	—
	100	100	100	100	100*

We see in the above table how very wide the differences may be in the proportions of all the compounds of lime which exist in marls of different kinds and from different localities. The first of those above mentioned—that from Luneburg—is not only very rich in carbonate of lime, but contains nearly 2½ per cent. of phosphate, which renders it peculiarly valuable.

That from Osnabruck, in the fourth column, is remarkable for containing nearly 7½ per cent. of sulphuret of

* These analyses were made by Sprengel.

iron (iron pyrites). When exposed to the air this pyrites decomposes and converts a portion of the lime into sulphate of lime (gypsum), and thus renders the marl more valuable for certain kinds of crops.

The following table shows that similar differences prevail also among dry marls from other parts of the world:

	Clay marl.	Powdery marls.		
	Ayrshire.	Banks of the Boyne.		Barbadoes
		White.	Blue.	
Carbonate of lime	8·4]	92·2	10·7	93·2
Phosphate of lime	?	?	?	0·1
Carbonate of magnesia...	—	1·1	—	—
Oxide of iron & alumina	2·2	—	4·1	1·6
Organic matter	2·8	1·4	1·1	0·5
Clay and siliceous matter	84·9	3·1	80·1	4·6
Water	1·4	1·5	2·0	—
	99·7	99·3	98·0	100

The marls from the banks of the Boyne have been formed from the finer parts of the decayed mountain limestone rocks of Ireland, deposited in the valley through which the Boyne flows, and in different localities mixed with more or less of the fine clay washed down the river along with it.

2°. The *wet* or peaty marls are not in general mixed with so much clay, but they not unfrequently contain a considerable per-centage of decayed vegetable or peaty matter. This appears from the following analyses of three varieties of such marl, after being perfectly dried:

	COMPOSITION OF PEATY MARLS FROM		
	Caithness.	Logie, Forfarshire.	
		top of the bed.	bottom.
Carbonate of lime	84·7	77·6	81·7
Oxide of iron & alumina	1·6	1·8	0·6
Organic matter	4·5	14·6	14·6
Insoluble, chiefly siliceous matter	9·2	6·0	3·1
	100	100	100

The organic matter in these marls, when made into composts, renders them more valuable to soils which are poor in vegetable matter than the pure white powdery marls, in which scarcely any organic matter is present.

The large quantity of water which these marls generally retain, and for so long a time, is, as I have already mentioned, so great a drawback to their sale and usefulness, from the cost of cartage which it involves, that it is very desirable to dry or burn them, in some cheap way by means of the peat along with which they are found. After being burned with peat the Logie marl above analysed was found to contain a large per-centage of gypsum, as appears in the following statement of its composition :—

	Logie marl, burned with peat.
Carbonate of lime	82·2
Sulphate of lime (gypsum)	8·6
Oxide of iron and alumina	1·2
Siliceous matter	5·7
Organic matter	1·0
	98·7

This gypsum will render the marl more valuable, especially as a top-dressing for grass and clover. Other advantages, therefore, besides the mere diminution in weight would result from even the partial burning of these peaty marls.

SECTION IV.—OF THE ORIGIN OF MARL BEDS.

Beds of marl are generally met with in hollows, near the foot of hills, or in the lower parts of vallies, the sites of ancient lakes, of greater or less extent. The waters of these lakes have been impregnated with lime which has gradually been deposited upon the bottom—until, in the lapse of time, it has formed the existing beds of marl.

There are two circumstances in connection with the deposition of marl beds, which are worthy of consideration :—

1°. The source of the lime.

2°. The way in which it is deposited or thrown down to the bottom of the lake.

I shall advert to these points in succession.

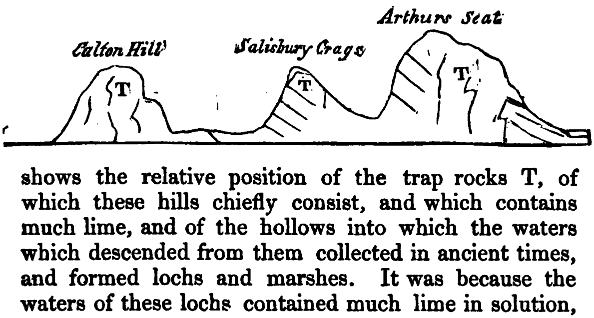
1°. *The source of the lime.*—The lakes in the bottoms of the vallies are fed by streams or springs from the hills, or by the waters which, after rain, sink through the soil and rocks, and find their way to the lowest level. The waters which thus reach the lake must bring the lime with them, either in the state of a fine suspended mud or in a state of solution.

If a heavy fall of rain descend upon a range of chalk hills or downs, we can easily understand that the flooded streams may become milky by the fine particles of chalk they will wash away with them. But when these streams empty themselves into a lake, where the waters are comparatively still, the fine chalk will settle to the bottom, and form a layer of marl, which will be increased by every new flood, till at length it becomes a bed of appreciable thickness. In chalk countries, and in other districts where soft limestones abound, extensive deposits of marl have been formed by this purely mechanical process.

But the greater part of our marl beds have been deposited from waters holding lime in a state of solution (p. 4). When lime abounds in the rocks of which the hills of a country are composed, the waters that descend along their sides, or flow from them in springs, are always to a considerable extent charged with lime. It is a common character of those limestone rocks, to which the name of carboniferous or mountain limestone is given, to be traversed by frequent fissures often of great depth, from which copious springs not unfrequently issue, and the waters of such springs almost in-

variably contain a large quantity of lime. Such copious springs gush out at intervals along the base of the Penine range of limestone hills which form the western borders of Yorkshire. In rocks also among which limestone does not appear in distinct and workable beds, it is often so generally diffused that the waters which issue from them always hold lime in solution. This is the case not only among such as are called *stratified* rocks—because they occur in beds or strata lying over one another—but in those masses of trap or whin-stone of various kinds, which do not lie in beds, but which often form whole ranges of hills, like the Ochill and part of the Pentland ranges in Scotland. These trap-rocks almost invariably contain a considerable proportion of lime disseminated through them, and hence the waters which flow over or pass through them are rarely free from a considerable proportion of lime.

The following imaginary section from Arthur's seat to the Calton-hill, in the neighbourhood of Edinburgh,



shows the relative position of the trap rocks T, of which these hills chiefly consist, and which contains much lime, and of the hollows into which the waters which descended from them collected in ancient times, and formed lochs and marshes. It was because the waters of these lochs contained much lime in solution, that the bottoms of all the deep hollows around Edinburgh, though now drained, are covered with beds of shelly marl of greater or less thickness, sometimes also overlaid by many feet of moss.

The following section again, across the valley of

Strathmore, shows the relative position of certain stratified and unstratified rocks, which both co-operate towards the production of beds of marl.

In this section 1, 2, 3 represent the relative positions of the three kinds of rock which form what is called the Old Red-sandstone formation in that district,—the faint lines over 1 being certain thin and marly strata, in which beds of lime abound. In both 1 and 3 limestones occur, so that the springs that issue from both are more or less calcareous, but they are more plentiful in the upper part of 1.

The rock T is the trap which on the one side of the valley lies under the Sidlaw hills, and has probably been the means of lifting them up, while on the other side it comes to day and forms the surface of the hilly country; *t t* are beds and masses of trap which are met with among the rocks 3, about the top of the Sidlaws. These trap rocks as they decay also yield lime to the water that passes through them—so that in this locality both the stratified and the unstratified rocks contribute to give to the waters a highly calcareous character—and hence the numerous beds of wet and peaty marl which are found in the hollows at various places along this beautiful and extensive valley.

The presence of lime in waters thus loaded with it is in our climate shown naturally by the *water-cress*, which lines the sides, or plants itself over the entire bottom of the shallow stream and accompanies it along its whole course from its native hills till it empties itself into the larger river, or into the comparatively stagnant lake. In practice it is easily detected by the hardness of the

water, by the difficulty of washing in it with soap,* and by the deposit it forms when boiled.

These calcareous waters descend into the hollows and form lakes or marshes. But how is the lime they hold in solution separated from them and deposited in the form of marl?

2°. *How is this lime deposited?*—There are three causes by which, under different circumstances, the lime is separated from the water.

a. When the waters fall into a lake or hollow which has no outlet, the level of the lake must be kept down by evaporation only. As much water must rise in vapour into the air as runs in from the springs or brooks. But the water which thus rises leaves behind it the lime and other substances it has held in solution—and if the lime is abundant it must fall to the bottom and produce a deposit of marl.

b. Or, if the waters as they fall into the basin hold lime in solution in consequence of the excess of carbonic acid present in them, then by prolonged exposure to the air, and especially during sunshine (Morren), this carbonic acid will diminish in quantity, and, consequently, insoluble carbonate of lime will separate. If a rapid river rush through the lake, the fine powder which thus falls may be swept away, but if the waters be still it will gradually subside and form a marl bed at the bottom.

c. It is observed that in limestone districts and in the hedge-rows of fields which have been long and plentifully limed, land snails abound and other animals which live in shells.† They do thus abound and multiply, be-

* The *comparative* hardness of any number of waters may be ascertained by dissolving Castile soap in spirit of wine, and pouring a little of the solution into the several waters. That which forms the most curd, when shaken, or is the most milky, contains the most lime.

† Of these the *Helix virgata* is especially abundant near the coast about Whitsand Bay, in Cornwall, and in the south of Devonshire. It is a prevailing opinion in these places that they contribute not a little to fatten sheep, the ground being literally covered with them.

cause the materials for the construction of their shells are easily and plentifully obtained.

So it is with the shell fish of our fresh water lakes, rivers, and ditches. They appear in greatest numbers in the waters from which, besides their own food, they can most abundantly obtain the materials for the construction of their shells. Hence the reason why they abound in some lakes and are rare in others. Some mountain streams are almost entirely free from lime, and hence few or no fresh water shells are met with even in the lakes into which they fall. But where lime is present they extract it from the water, build it up into their shells, and when they die leave these solid shells at the bottom to accumulate and solidify into beds of marl. Hence many of our fresh water marls, especially those wet marls which cover the bottoms of all the old lakes and deep hollows in the neighbourhood of Edinburgh, and which lie below beds of peat in Ayrshire, Forfarshire, and Caithness, are in great part composed of the visible fragments of shells of various kinds and sizes.

d. But waters rich in lime abound not merely in shell fish properly so called, and such as I have now described, but in minute forms of animal life also which escape the unaided eye. A fine chalky mud collects at the bottom of a lake, and we fancy it must consist of minute particles of carbonate of lime, which have formerly been held in solution by the water, and have been separated from it by some merely mechanical or chemical form of deposition, such as those above described (*a* and *b*). But put a little of this mud under the microscope and it is instantly seen to consist of myriads of minute shells, the former residences of creatures far too small for the human eye to perceive. Take up now a drop of the transparent and apparently pure water, and dry it upon a bit of glass, a white stain will be left almost invisible to the naked eye. But examine this stain by the aid of the microscope, and in it will be recognised many

of the same forms as were previously discovered in the marl.

Thus those minute animals still live, still swarm in the waters. It is their invisible shells which, as generation after generation died, have collected in such vast quantities as to form beds of marl of many feet in thickness.

To these minute creatures the name of *infusorial* animals has been given. Some of them are so minute, that a cubic inch of stone has been calculated to contain the remains of 41 thousand millions of them—and yet deposits composed almost entirely of such remains have been met with of 20 and 30 feet in thickness. How very striking it is to find the united labours of these invisible creatures capable of producing such extraordinary effects! How very little we really know of what is going on around us!

Thus marl beds of fresh water origin may be produced by mechanical deposition caused by the gradual evaporation of water containing lime,—by chemical deposition when the carbonic acid by which it is held in solution is given off into the air, or decomposed by the sunshine —by the accumulation of the dried shells of visible animals which have lived in the water—and by the deposition of the minute shields and shells of invisible creatures which float in countless numbers in every stagnant pool. Of these causes the last is probably the most extensively prevalent and that by which the largest deposits of marl have been produced.

In the above remarks I have spoken only of fresh water marls. But deposits of marl mixed with marine shells are constantly taking place at present at the bottom of the sea, and many flat (Carse of Stirling) and hollow-inland tracts of land which have been formerly beneath the sea are found to be covered by such beds of marine marls at a greater or less depth below the present level of the land. The remarks made above in regard to fresh water, apply equally to the sea. The same mechanical and

chemical causes operate to throw down lime—the shells of animals, only of different species, are deposited in vast numbers—and infusorial animals float in every sea, and deposit their dead skeletons, shields and shells, in every bay and estuary.*

SECTION V.—OF SHELL AND CORAL SANDS.

Shell and coral sand are forms in which in some parts of the world lime is largely laid upon the land.

1°. *Shell sand.*—The sands that skirt the shores of the sea are found in many localities to be composed, in large proportion, of the fragments of broken and comminuted shells. These form a calcareous sand, mixed occasionally with portions of animal matter, and, when taken fresh from the sea-shore, with some saline matter derived from the sea.

Such is the case in many places on the coast of Cornwall. From these spots the sand is transported to a distance of many miles into the interior for the purpose of being laid upon the land. It has been estimated† that seven millions of cubic feet are at present employed every year in that county for this purpose.

On the western coast of Scotland also, and on the shores of the island of Arran and of the Western Isles, this shell sand abounds, and is applied extensively, and

* On a recent occasion, when the Leith Docks were cleaned out, a large quantity of black mud was collected, which was carted away by the neighbouring farmers. A portion of it being sent to me for an opinion as to its value, I found it to contain a considerable quantity of animal matter, with much finely-divided silica. Suspecting this to consist of the remains of infusoria, I submitted it, with the original mud, to the microscopal skill of my friend Dr. Stark, who found the mud to consist, in large proportion, of living and dead infusoria, of some of which the siliceous matter formed the skeletons. These infusoria, therefore, now abound in the waters of the harbour of Leith.

† De la Beche's *Geological Report on Cornwall, &c.*, p. 480.

with remarkably beneficial effects, both to the pasture lands and to the peaty soils that cover so large an area in this remote part of Scotland. It is chiefly along the coasts that it has hitherto been extensively employed, and it is transported by sea to a distance of 80 or 100 miles. "In the island of Barray alone, there are four square miles of shells and shell sand of the finest quality and of an indefinite depth."* When covered with a dressing of this shell sand the surface of the peaty land becomes overspread with a sward of delicate grass—and the border of green herbage that skirts the shores of these islands in so many places is to be ascribed either to the artifical application of such a dressing or to the natural action of the sea winds in strewing the fine sand over them, when seasons of storm occur.

This beneficial action of the winds is seen to advantage in the low flat island of Tiree. The sea winds sweep right across nearly the whole of it, and thus spread a thin and even covering of fine shell sand over its surface. Thus it is gradually raised above the sea, while at the same time its cultivation can be kept up.† But at the northern end of Tiree and in the Island of Coll, where rocky hills arrest the winds, the shell sand accumulates and forms a barren waste.

The coast of Ireland is no less rich in shell sand in many parts both of its northern and southern coasts. A century and a half ago, it is known to have been used for agricultural purposes in the north of Ireland—and nearly as long ago to have been brought across to the opposite Galloway coast of Scotland with the view of being applied to the land (Macdonald).

On the coasts of France, and especially in Britany—on the other side of the English channel, opposite to

* Macdonald's *Agricultural Survey of the Hebrides*, p. 401.

† The inhabitants grow and export bear, and import oat meal in return (James Wilson).

Cornwall—it is obtained in large quantity, and is in great demand. It is applied to the clay soils and to marshy grass lands with much advantage, and is carried far inland for this purpose. It is there called *trez*, and is laid on the land at the rate of 10 to 15 tons per acre. On the southern coasts of France, where shell sand is met with, it is known by the name of *tanque* or *tangue*.

The shell sand of Cornwall contains from 40 to 70 per cent. of carbonate of lime, with an equally variable small admixture of animal matter and of sea salt. The rest is chiefly siliceous sand. Two specimens of *tangue* from the south of France, analysed by Vitalis, and one of shell sand from the Island of Isla, examined by myself, consisted of

	Tangue, from the South of France.		Shell sand from Isla.
Sand, chiefly siliceous	20·3	40	71·7 to 65·7
Alumina and oxide of iron...	4·6	4·6	
Carbonate of lime	66·0	47·5	28·0 to 34·0
Phosphate of lime	?	?	0·3 0·3
Water, and loss	9·1	7·9	—— ——
	100	100	100 100

3°. *Coral sand* is similar in its nature to the shell sand with which it is often intermixed on the sea-shore. It is collected in considerable quantities, however, by the aid of the drag—being torn up by the fishermen in a living state—on the south coasts of Ireland (Bantry Bay and elsewhere), and on the shores of Britany, especially near the mouths of the rivers. According to Mrs. Hall, the coral sand raised in Bantry Bay alone produces £4000. or £5000. a year to the boatmen who procure it and to the peasants who convey it up the country.

The coral sand is preferred by the farmer in the fresh state, probably because it contains both more saline and more animal matter than after it has been for some time

exposed to the air. This animal matter—derived from the bodies of the minute animals which form the coral—enables it to unite in some measure the beneficial effects which follow from the application of marl and of a small dressing of farm-yard or other valuable mixed manure.

Payen and Boussingault ascribe the principal efficacy of the shell and coral sands to the small quantity of animal matter which is present in them. These chemists estimate the relative manuring powers of different substances applied to the land by the quantities of nitrogen which they severally contain, and thus, compared with farm-yard manure, attribute to the shell and coral sands the following relative values :—

	Contain of nitrogen.	Relative values.
100 lbs. of farm-yard manure	0·40 lbs.	100
...... of coral sand (*Merl*)	0·512 lbs.	128
...... of shell sand (*Trez*)	0·13 lbs.	32½*

That is to say, that, in so far as the action of these substances is dependent upon the nitrogen they contain, fresh *coral* sand is nearly one-third more valuable than farm-yard manure, while fresh *shell* sand is only equal in virtue to one-third of its weight of the same substance.

Though much reliance is not to be placed upon this method of estimating the relative values of manuring substances, yet the fact, that so much animal matter is occasionally present in the living corals, accounts in part for the *immediate* effects of this form of calcareous application. This animal matter acts directly and during the first year; the carbonate of lime begins to shew its beneficial influence most distinctly when two or three years have passed.

3°. *Infusorial sand.*—Under this name I wish to give

* *Annales de Chim. et de Phys., third series,* iii., p. 103.

a separate notice of a kind of fine mealy-looking sea sand used extensively in Normandy upon the light sandy soils, and which is often carted many miles inland. Mr. Lorimer, of Aberdalgie, in a late excursion along the coast of Normandy, was struck by the preference which was given by the local farmers to this fine meal over the banks of shell sand which abound also on the coast, and he sent me a portion of it for examination. Upon analysis it was found to consist of—

Organic matter	5·06
Chloride of sodium (common salt)	1·01
Gypsum	0·32
Chloride of calcium	0·73
Magnesia...	trace.
Carbonate of lime	43·50
Alumina	0·17
Oxide of iron	1·20
Oxide of manganese	trace.
Insoluble siliceous matter	47·69
	99·68

From this analysis it appears that the value of this mealy sand does not depend solely upon the lime (43½ per cent.) it contains, but is derived in some measure also from the 5 per cent. of organic matter, and the 2 per cent. of soluble salts which are present in it. It is remarkable, also, for containing nearly half its weight (48 per cent.) of siliceous matter in the state of an exceedingly fine powder.

When examined under the microscope, this sand is seen to consist of minute crystals of carbonate of lime, of broken limbs and claws of small crustaceous animals, and of the shells or sheaths of numberless infusoria (Dr. Stark). These shells or sheaths belong in large proportion to species which absorb silica from the water instead of lime, and form flinty instead of calcareous shells or sheaths. Hence the source of the siliceous and organic matters which this lime sand contains.

Its value over the coarser shell sand, therefore, consists in its organic matter and soluble salts, and in the

minute state of division in which its particles are found. This fine powdery state enables it to be mixed more intimately with the soil—causes an equal weight to go further—and prevents it from opening and rendering still lighter the sandy soils of the country as the coarse shells would be apt to do. In Normandy it is generally applied in the form of compost, and is extensively mixed with the farm-yard manure, which it is said greatly to improve.

SECTION VI.—OF LIMESTONE SAND AND GRAVEL AND OF CRUSHED LIMESTONE.

1°. *Limestone sand and gravel.*—In countries which abound in beds or hills of limestone, there are found scattered here and there, in the hollows and on the hill sides, banks and rounded heaps of sand and gravel, in which fragments of limestone abound. These are distinguished by the names of limestone sand and gravel, and are derived from the decay or wearing down of the limestone and other rocks by the action of water. Such accumulations are frequent in Ireland. They are indeed extensively diffused over the surface of that island, as we might expect in a country abounding so much in rocks of mountain limestone. In the neighbourhood of peat bogs these sands and gravels are a real blessing. They are a ready, most useful, and largely employed means of improvement, producing, upon arable land, the ordinary effects of liming, and, when spread upon boggy soils, enabling it, without other assistance, to grow sweet herbage and to afford a nourishing pasture. The proportion of carbonate of lime which these sands and gravels contain is very variable. I have examined two varieties from Kilfinane, in the county of Limerick—the one, a yellow sand, contained 26 per cent. of carbonate of lime, the residue, being a fine red sand, chiefly siliceous—the other, a fine gravel of a grey colour, con-

tained 40 per cent. of carbonate of lime in the form chiefly of rounded fragments of blue limestone, the residue consisting of fragments of sandstone, of quartz, and of granite.

The application of these mixed sands will not only consolidate and otherwise improve the physical character of the soil, but will greatly benefit its chemical composition. The fragments of granite, containing undecomposed felspar and mica, will supply potash, and perhaps magnesia, to the growing plants, and will thus materially aid the fertilizing action of the limestone sand with which they are mixed.

2°. *Crushed limestone.*—It was probably the good effects which were seen in the Western isles to follow from the drifting of the shell sand upon the mossy fields, and from the application of the limestone gravel in Ireland, that suggested to Lord Kames and others the application of crushed limestone to similar land in the remote districts of Scotland. There are numerous places in which limestone and water power abound together, but where coal is so scarce and dear that it would be impossible to reduce the limestone by the ordinary method of burning. In such localities the erection of a pair of crushing rollers, such as are used at our lead and copper mines, to be turned by water power, would be an economical method of obtaining the means of liming and improving the land. I have been in Highland districts, remote from coal, where miles of hill pasture promised to double their value, if open drained and limed, while every here and there copious streams flowed down the hill sides, over beds of limestone rock. How easily here, and how cheaply, might the means of improvement be made available! Many years ago, I believe at the suggestion of Lord Kames, this mode of crushing was adopted on the estate of Struan in Rannoch, Perthshire. I do not know for what reason it was afterwards abandoned.

There are also many localities, in which rocks, rich in calcareous matter, abound, which are nevertheless so impure—contain so much earthy matter—that they cannot be burned into lime. The abundance and cheapness of fuel in such districts will not aid the farmer. He must still bring his lime from a great distance, and probably at a great expense. But if the rocks in his own neighbourhood were crushed, they might afford him a cheap and valuable dressing for his land. I am satisfied that there are many places in which limestones of this impure character—which are really useless for building purposes—which do not fall to powder when burned, and have therefore been hitherto neglected as useless—might by crushing be made extensively useful for agricultural purposes. The siliceous limestones of the millstone grit, and of the old red-sandstone (corn-stones)—the earthy calcareous beds of the mountain limestone and many of the calcareous strata of the silurian rocks, might thus be made to improve more extensively the localities in which they are severally met with. The rich limes, now brought from a great distance, and at much expense, might be in a great measure superseded by the use of the native produce of the district.

SECTION VII.—OF THE USE OF CHALK.

Chalk is another form of carbonate of lime, which occurs very abundantly in nature, and which, from its softness, has in many parts of England been largely applied, and with much success, in liming the land.

The practice of chalking prevails more or less extensively in all that part of England over which the chalk formation extends. It is usually dug up from pits towards the close of autumn or the beginning of spring, when full of water, and laid upon the land in lumps. During the winter's alternate frost and thaw the lumps

of chalk fall to pieces and are readily spread over the fields in spring. It is the porosity of the chalk that fits it for being applied in this way to the land. It drinks in and retains the rain-water in its pores; this water freezes in winter, and expands in all directions, the particles of chalk are therefore torn asunder from each other, and, when the thaw comes, fall to powder. If the chalk be dry it does not fall to powder, and cannot, therefore, be equally spread over the field or mixed with the soil.

I am not sufficiently acquainted with the chalk districts to know upon what principle the application of these top-dressings of chalk is usually made by the practical man. In Hampshire, I am informed that it is never applied to the thin soils, resting on chalk, except when they are supposed to be nearly deficient in calcareous matter, or, as it is called there, *wood-sour*. I do not know, however, whether the practice of farmers in other districts is uniformly regulated by the same principle.

The application of chalk to the chalk downs in the south of England, and to the wolds of Lincolnshire and Yorkshire, is of very old date, and experience has shown that repeated top-dressings of chalk may be made with advantage, even upon thin soils of a few inches, which rest immediately upon beds of chalk. It is a singular fact that the thin black soil of the South Downs sometimes contain scarcely a trace of lime; upon breaking them up, the first thing done is usually to dress them with chalk.

Where chalking is extensively practised, the deeper beds of chalk are in general preferred. Pits are sunk to a considerable depth, and the chalk which is raised from them has long been reckoned more beneficial than that which lies nearer the surface. The farmer who will apply many tons per acre of this under chalk would refuse to bring up with his plough a single inch of that

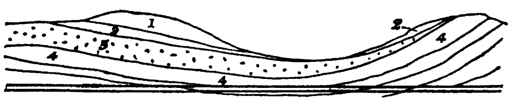
which lies immediately beneath the thin covering through which his plough is yearly drawn.

So much is this the case that the chalk of an entire district is sometimes rejected by the farmer, and he will rather bring another variety from a great distance, than incur the less expense of laying on his land that which is met with on his own or his neighbour's farm. Thus, the Suffolk farmers prefer the chalk of Kent to lay upon their lands, and are at the cost of bringing it across the estuary of the Thames, though chalk rocks lie every where around and beneath them.

The reason of this practice is no doubt founded upon some chemical difference between the upper and the under chalks, which has not hitherto been investigated by analysis.

The relative position of these beds of chalk is represented in the following diagram :—

Suffolk. Mouth of the Thames. Kent.



in which the bed 1 represents the London clay; 2, the plastic clay immediately below it; 3, the upper chalk, with flints rising to the surface in Suffolk; and 4, the lower chalk, without flints, which lies too deep to be reached by the Suffolk farmers, though it comes to the surface in Kent, and is there abundant and easily accessible. The under beds, which are free from flint, produce naturally a stiffer, a more tenacious, and a more fertile soil than the upper chalk; and hence, probably, the benefits which follow from their application to the thin and poor soils of the latter. Still the precise chemical differences between the two are not yet understood, and it is very desirable that they should be investigated (see p. 30).

Where these upper chalks form the surface, there

is a very general,—perhaps in many places a well-founded—prejudice, against bringing up any fresh chalk with the plough. The cultivator prefers to work on with his shallow soil, rather than by attempting to deepen it, to run the risk of injuring his land. But the enlightened opinions which are now every where spreading in regard to the importance of depth of soil are gradually leading enterprising agriculturists to break through old customs, and to try, in a more skilful manner, those means of improvement which have hitherto, from local reasons, been considered inapplicable to the district in which they live. A very bold step of this kind has, among others, been taken by Mr. Hewitt Davis, at Seldon farm, near Croydon, in Surrey, which rests upon the upper chalk. With the view of deepening a soil of six inches, he has brought to the surface seven or eight inches of pure chalk, after having drained it to a depth of not less than three feet. The immediate effect he informs me is not striking, but certainly not dis-advantageous to the land. He has been enabled, however, now that time has mouldered it, to grow deep rooted crops of clover, beans, cabbage, and swedes, which throve but poorly before, and to *treble* the value of the land. There is certainly a large field for useful improvement in the chalk districts, if pure chalk can be ploughed up in this way with benefit to the soil and a profitable return to the farmer.

CHAPTER II.

Artificial states in which lime is applied to the soil. Varieties of limestone. Composition of chalk, nodular limestones, blue limestones, and magnesian limestones. Burning and slaking of lime. Composition of slaked lime and magnesia. Chemical changes which slaked lime and magnesia undergo when exposed to the air. Lime composts, lime and salt, and refuse lime of the gas-works.

In the preceding chapter I have described all the natural forms in which lime is applied to the land without previous preparation. The solid limestone rocks are more extensively employed in this country than any other form in which lime occurs—but they require the previous preparation of burning. In the present chapter, therefore, I shall treat of the different kinds of limestone, and the changes which they undergo when burned, slaked, and afterwards spread upon the land.

SECTION I.—OF THE DIFFERENT VARIETIES OF LIMESTONE.

There are four principal varieties of limestone found in our islands—chalk, nodular limestones, blue and black limestones, and magnesian limestones.

1°. *Chalk* is a white limestone, which in England is generally soft, porous, and earthy in its fracture, adheres to the tongue, and falls to pieces under the action of the winter's frost. It can, therefore, be laid upon the land, as I have already described (p. 26), without

any previous preparation. In the north of Ireland, again, the chalk is hard, compact, and brittle. It scarcely absorbs any water, and is therefore unaffected by the frost. Before it can be used for any agricultural purpose, it must be burned in lime-kilns in the usual way.

Few analyses of different varieties of chalk, made with especial reference to their agricultural values, have hitherto been published. We are therefore as yet very imperfectly acquainted with the proportions especially of sulphate and phosphate of lime usually present in them. In a subsequent chapter I shall state all that we at present know in regard to the quantity of phosphate they contain.

The upper chalk, as we have seen (p. 27), abounds in flints, but the white chalk itself, in which the flints are imbedded, contains very little siliceous matter—often not more than half a per cent. The following analyses are among the best we yet possess of this variety of limestone :—

	Upper chalk of Meudon. Berthier.	Intermediate chalk of Maestricht.	White chalk marl. Osnabruck.	Gray chalk marl, of the Kromsberg.	near Rethen.*
Carbonate of lime	98	96·5	26	86·5	85·5
Carbonate of magnesia	1	1·0	—	—	0·5
Alumina and oxide of iron	1	0·5	7	4·0	3·0
Silica	—	0·5	59	5·5	6·0
Water	—	1·5	8	4·0	5·0
	100	100	100	100	100

It is not common in this country to find beds of chalk containing so much siliceous matter as that from Osnabruck, of which the composition is given in the third column of the above table. These analyses appear to show that the quantity of magnesia contained by the chalk rocks is usually small.

* The four latter of these analyses are by Römer.

It has been shown by Ehrenberg that the chalk rocks are made up in large proportion of the remains of minute infusorial and other animals, such as those of which I have spoken when treating of the origin of beds of marl (p. 18). It is probable, therefore, that all the chalks contain an appreciable quantity of phosphate of lime—which is present in all animals—but that this proportion will vary with the kind of animals from the remains of which it has in different localities been principally made up.

2°. *Nodular limestone.*—In some parts of England limestone occurs in rounded balls or nodules, scattered at intervals through a hardened rock of clay. In the lias clays of Whitby, Lyme Regis, and other places, they especially abound. When burned in kilns these nodules often refuse to fall to powder by slaking, in consequence of the large quantity of earthy matter they contain. When ground to powder, however, after burning, they quickly set, and make excellent cements, for which purpose they are chiefly employed. Three varieties of these nodules gave by analysis to Mr. Phillips—

	Aberthaw.	Yorkshire.	Sheppy.
Carbonate of lime ...	86	62	66
Clay	11	34	32
	97	96	98

In other parts of the island, again—as in Morayshire, where the old-red sandstone forms the prevailing rock—nodular limestones occur, which are of a very fine quality, and burn into excellent lime. These are dug up wherever they are met with in sufficient quantity, and are burnéd for agricultural purposes. None of these nodular limestones of the old-red sandstones have yet been analysed, but from their abounding in the remains of fossil fishes, it is to be presumed that they will be comparatively rich in the valuable *phosphate* of lime.

3°. *Blue and black limestones.*—In Great Britain these

limestones principally occur in the mountainous or hilly districts of Derby, York, Northumberland, Ayr, Fife, and the Lothians—but in Ireland they are found over the whole central part of the island. They compose what are usually called the mountain or carboniferous limestone beds.

These limestones are hard, compact, and brittle. They are generally blue in colour, but are sometimes black—as in the black marble of Derbyshire. They are usually loaded with, often entirely made up of, the remains of marine animals of considerable size. Some beds of great thickness appear to consist of one entire mass of shells of various kinds, others to be the work of coralline insects—to be in fact ancient coral reefs. They owe their colour to a portion of the organic matter of those animals which still remains imbedded in the rock, and the colour varies in general with the proportion of this matter which they have retained.

Differing thus in the nature of the animal remains of which they consist, it is to be expected that they will differ considerably also in the relative proportions, especially of those substances of which only a small quantity is usually found in them.

Most of the analyses of these limestones, hitherto published, have been made with the view of determining only the per-centage of pure carbonate of lime and of earthy matter they contained—or of estimating the relative proportions of lime and magnesia. But the progress of scientific agriculture now demands a more rigorous procedure. The importance of the phosphate of lime being now understood, a more refined analysis of such limestones must hereafter be made if their true agricultural value is to be determined. This makes the aid of a higher chemistry necessary to the farmer, since the rigorous determination of the very small proportion

of phosphoric acid which these limestones usually contain is a work of very considerable difficulty.*

The following analyses of two blue limestones from the neighbourhood of Stanhope, in the county of Durham, were made with the view of determining the relative proportions of lime and magnesia which they respectively contained—

	LIMESTONES FROM STANHOPE.	
	Shelly variety.	Coralline variety.
Carbonate of lime	95·06 ...	93·77
Carbonate of magnesia ...	2·46 ...	0·37
Alumina and oxides of iron ...	1·00 ...	3·87
Insoluble siliceous matter ...	1·32 ...	1·59
	99·84	99·60

These are both rich limes—excellently adapted for agricultural purposes—containing only a small quantity of earthy matter, and not too large a proportion of magnesia. The per-centage of phosphate of lime was not sought for. We know, however, from the analyses of Silliman, that the recent corals contain the phosphates of lime and magnesia: there can be no doubt, therefore, that they are also present in the ancient corals preserved in these limestone rocks. In the absence of rigorous comparative analyses, therefore, we should expect that the coralline variety would be richer in phosphates than the shelly variety of these Stanhope and other mountain limestones.

The quantity of magnesia in these blue limestones varies very much. In the same quarry one bed of rock will be almost free from magnesia, in another a large per-centage will be found.

This variation in the proportion of magnesia in dif-

* The proportions of phosphate of lime in a number of different varieties of limestone, recently examined in my laboratory with a view to the determination of this point, will be found in a subsequent chapter.

ferent limestones and in different beds appears in the following table, representing the composition of three Scottish limestones, of nearly the same geological age —being under or among the coal measures respectively of Fife and the Lothians, and of one limestone from the Hudson river, in the United States :—

	LIMESTONE OF BROXBURN. Upper bed.	Lower bed.	BLAIR ADAM.	RONDONT, HUDSON.
Carbonate of lime ...	56·32	62·72	60·63	45·30
Lime, in state of silicate	0·18	0·83	—	—
Carbonate of magnesia	2·14	7·89	13·19	25·70
Oxides of iron	3·36	3·95	8·01	2·25
Soluble alumina ...	0·22	0·18	0·70	9·13
Alumina, in state of silicate	15·02	2·11	16·14	
Silica	21·08	20·13		15·37
Water	1·90	0·98	0·30	2·25
	100·22	98·79	98·97*	100

These limestones, from the large quantity of magnesia and earthy matter they contain, are well adapted for hydraulic limes—a purpose for which those of Broxburn are extensively employed. They contain too little lime to be reckoned among the best for agricultural purposes, and the large per-centage of magnesia, in the Blair Adam and Rondont limes, will prove an objection to their application in very large doses to the land.

The earthy matter varies very much in quantity, as is seen in the above analyses of the limestones from Broxburn. But in some beds it is so great that, when burned, the limestone refuses to fall to powder. The Irish *calp* is of this kind, and similar calcareous beds occur in various parts of the Mountain limestone and in the older Silurian rocks. Such beds of rock may be employed like the nodular limestone of the lias clays (p. 31) for the manufacture of cements and hydraulic mortars, but cannot be used in the usual way for the im-

* The three Scottish limestones were analysed by my assistant, Mr. Fromberg—the fourth by Professor Beck.

provement of the soil. There are many districts, however, in which, as I have stated in the preceding chapter (p. 25), such limestones might be cheaply crushed, and thus economically prepared for being laid upon the land.

4°. *Magnesian limestones.*—These limestones derive their name from the large proportion of magnesia they usually contain. In England they cover a narrow stripe of country, often hilly or high, running from north to south, and extending from near the city of Durham to the town of Nottingham. They are, in this country, generally of a yellow colour, often earthy in their fracture, sometimes soft and friable like marl. In these states they form bad building stones, but do not fall to pieces during the winter's frost and thaw. They cannot, therefore, be applied directly, like the chalk rocks, in liming the land.

When hard and brittle, these limestones are sometimes honey-combed, as at Sunderland, in the county of Durham, but are more usually studded with cavities of various sizes, the interior of which is lined with crystals, generally of carbonate of lime. In some localities, however, the rock occurs of a compact and crystalline structure, which enables it to withstand the action of the weather in a remarkable manner, and thus to unite most of the desirable qualities of a good and durable building stone. It is from a bed of magnesian limestone of this description in Yorkshire that the stones for the new houses of parliament are procured.

In this limestone comparatively few animal remains have hitherto been found. Shells occur only in a few places, of comparatively few species, and seldom in great numbers. Corals also are unfrequent, and in the county of Durham I have met with them only on a few of the higher hills of this formation. The most abundant locality for shells and corals is Humbledon Hill, near Sunderland, but even there they occur only over a limited space.

This scarcity of organic remains may probably be attended in these limestones by a similar scarcity of the phosphate of lime, which is found always to increase in quantity with that of the remains of certain forms of animal life. No analyses, however, have been hitherto published, the results of which enable us to speak with any degree of confidence upon this point.

The magnesia, like the lime in these rocks, is in combination with carbonic acid, forming *carbonate of magnesia*. One hundred pounds of this carbonate consist of

Carbonic acid	51·7
Magnesia	48·3
	100

or *one ton of pure dry carbonate of magnesia contains 9⅔ cwts. of magnesia*—the calcined magnesia of the shops.

The proportion of this carbonate in the magnesian limestones varies very much. In some it forms nearly one-half of their weight, while in others it is almost entirely wanting. Even in the same quarry different beds are found to contain very different proportions, and are worked, therefore, for different purposes.

The quantity of magnesia which any such limestone contains determines in a great degree its value, either for building or for agricultural purposes. The larger the proportion of magnesia the better it *binds* when used for mortar,—the smaller the proportion, the more safely in most districts of this country, and the more abundantly, can it be laid upon the land. Hence, most of the past analyses of these limestones have been made with the view of determining the relative proportions of lime and magnesia only. With this view chiefly were the following analyses made by myself, of magnesian limestones collected from different parts of the county of Durham :—

	Carbonate of Lime.	Carbonate of Magnesia.	Alumina, Oxide of Iron, and Phosphoric Acid.	Insoluble earthy matter.	Appearance of the specimen.
Garmondsway	97·5	2·5	trace.	trace.	Hard, compact, grey.
Stony-gate	98·0	1·61	0·27	0·12	Crystalline, fine grained, yellow.
Fulwell	95·0	2·1	0·3	2·6	Honey-combed, crystalline, yellow.
Seaham (A)	96·5	2·3	0·2	1·0	Hard, compact, fine-grained.
...... (B)	95·0	1·3	0·2	3·5	Hard, porous, brown.
Hartlepool	54·5	44·93	0·33	0·24	Oolitic, yellow.
Humbledon Hill (A)	57·9	41·8	?	0·28	Perfect encrinal columns.
.... (B)	60·41	38·78	?	0·81	Consisting in part of encrinal columns.
Ferryhill	54·1	44·72	1·58	4·6	Compact, yellowish.

The second column of the above table shews, as I have already stated, that the proportion of magnesia varies very much, and consequently that the agricultural value of this lime from different localities must vary also. The specimens analysed are all remarkably free from earthy matter, but it is to be regretted that the exact proportion of phosphoric acid, or of phosphate of lime, was not separately determined.

The simplest method of detecting magnesia in a limestone is to dissolve it in diluted muriatic acid, and then to pour clear lime water into the filtered solution. If a light white powder fall, it is magnesia. The relative proportions of magnesia in several limestones may be estimated pretty nearly by dissolving an equal weight of each, pouring the filtered solutions into separate bottles which can be corked, and then filling them all up

with clear lime water. On subsiding, the relative bulks of the precipitates in the bottles will indicate the richness of the several varieties in magnesia.

SECTION II.—OF THE BURNING AND SLAKING OF LIME AND MAGNESIA.

1°. *Burning.*—When the carbonates of lime or magnesia contained in common limestone are heated to a high temperature in the open air, the carbonic acid they contain is driven off by the heat, and the lime and magnesia remain behind in the caustic state. When heated in this way, the carbonate of magnesia parts with its carbonic acid more easily and at a lower temperature than the carbonate of lime.

Both also are decomposed more readily when a *current* of air is allowed to pass through the burning mass. Hence on the large scale this burning is performed in kilns especially built for the purpose. In lime-kilns with an opening below to admit the air, the limestone is burned much more effectually and at a much less cost of fuel than in those round *pies* which in limestone districts the farmer often builds up for the use of his own farm. The reason of this is that the current of air carries with it a quantity of watery vapour, which greatly promotes the separation of the carbonic acid from the lime.

When thus deprived of its carbonic acid by heat, the lime is known by the several names of burned lime, quick-lime, caustic-lime, and lime-shells.

One ton of good limestone yields about 11 cwt. of lime-shells. The weight of the shells per bushel varies with the kind of limestone and with the way in which it is burned. In some districts (Alnwick) the bushel does not weigh more than 75 lbs.; in others it approaches to a cwt. This is a great difference, and shows how uncertain the quantity applied to the land may be when

it is reckoned by the bushel. Lime should be both bought and laid on by weight.

2°. *Slaking.*—Burned lime has a strong tendency to drink in and combine with water. Hence when taken from the kiln and exposed to the air it absorbs moisture from the atmosphere, increases in weight, swells out, and gradually falls to powder. Or if water be thrown upon the shells, they drink it in, become hot, swell very much, and fall down in a short time to a bulky more or less white and almost impalpable powder. When the thirsty lime has thus fallen, it is said to be *slaked.* If more water be now added, it is not drunk in, but forms with the lime a paste or mortar.

There are three ways in which lime is slaked.

a. Spontaneous slaking.—When the shells are laid up in heaps in the air and are allowed to draw moisture from the atmosphere they fall to powder of themselves. This method is preferred in many districts. The lime is laid up in heaps, covered with sods, and left sometimes for months till it has completely fallen, or till the time is convenient for laying it upon the land. Thus it is often carted in winter, covered up in heaps, and applied to the land in summer when preparing for the green crop. The lime seldom becomes very hot when slaked in this way, unless a heavy shower of rain happen to fall, when the surface of the lime heaps sometimes becomes so hot as to char and even to set fire to the sods by which they are covered. When slaked spontaneously, rich limes increase in bulk three or three and a half times. Poorer limes—such as contain much earthy matter—may not do more than double their bulk.

b. Slaking by immersion.—In this mode of slaking, the lime is put into a basket or bucket, is dipped into water for a short time, and when taken out is left to fall in the air. This method is found to possess certain advantages for engineering purposes, but it is never adopted, I believe, by the practical farmer.

c. By pouring water upon it.—This is the ordinary method of slaking quickly and for building purposes. The heat given off during this mode of slaking is in rich limes often sufficient to kindle gunpowder. The heat, however, is less, and the slaking less rapid the longer the lime has been out of the kiln. Rich limes slaked in this way increase in bulk from two to three and a half times.

If the water be thrown on so rapidly or in so large a quantity as to *chill* the lime or any part of it, the powder will be gritty, will contain many little lumps which will refuse to slake, and will therefore be less bulky and less minutely divided.

The first of these methods is the best for agricultural purposes— and for the following among other reasons:—

a. It causes the lime to fall to the finest powder. It may be received indeed as a general rule that *that limestone or that mode of slaking is the best for agricultural purposes, which gives a slaked lime of the greatest bulk and in the most minute state of division.*

b. It is the least expensive, requires the least care and attention, and exposes the lime least to become chilled and gritty—but

c. When thus left to itself the lime heaps should be covered over with sods—*first,* to prevent the surface from being chilled, or the whole converted into mortar by large or continued falls of rain—and *second,* to exclude the too free access of the air which gradually brings back the lime to the state of carbonate, as will be explained in the following section.

SECTION III.—COMPOSITION OF SLAKED LIME AND MAGNESIA.

1°. *Slaked lime.*—When pure quicklime is thus slaked it *combines* chemically with a large quantity of water—

one ton of pure lime becoming 25 cwts. of slaked lime. This slaked lime is called by chemists *hydrate* of lime, and the pure hydrate contains in 100lbs.

Lime	76 pounds.
Water	24 pounds.
	100

Lime, however, is rarely so pure or so skilfully and perfectly slaked, as to take up the whole of this theoretical quantity. It seldom increases in weight so much as one-third.

2°. *Slaked magnesia.*—The caustic or calcined magnesia contained in lime shells also slakes and falls to powder when water is poured upon it, and forms a *hydrate* of magnesia. It likewise swells and becomes hot, but not in an equal degree with pure lime.

Pure hydrate of magnesia consists of

Magnesia	69·7
Water	30·3
	100

It increases in weight therefore in slaking more than lime does—one ton of caustic magnesia becoming nearly 29 cwts. of hydrate.

When limestones containing magnesia are burned and afterwards slaked, the fallen lime consists of a mixture of the above two hydrates in proportions which depend upon the chemical composition of the limestones.

An important difference between these two hydrates is, that the hydrate of magnesia will harden under water or in a wet soil in about eight days—forming a hydraulic cement. Hydrate of lime will not so harden, but a mixture of the two in the proportions in which they exist in the Hartlepool, Humbledon, and Ferryhill limestones will harden under water, and form a solid mass. In the minute state of division in which lime is applied to the soil, the particles, if it be a magnesian lime, will, in wet soils or in the event of rainy weather

ensuing immediately after its application, become granular and gritty, and cohere occasionally into lumps, on which the air will have little effect. This property is of considerable importance in connection with the further *chemical* changes which slaked limes undergo when exposed to the air or when buried in the soil.

SECTION IV.—CHANGES WHICH SLAKED LIME AND MAGNESIA UNDERGO BY PROLONGED EXPOSURE TO THE AIR.

When the hydrates of lime or magnesia obtained by slaking are exposed to the open air, they gradually absorb carbonic acid from the atmosphere, and tend to return to the same state of carbonate in which they existed previous to burning. By mere exposure to the air, however, unless they are in a minute state of division, and *the air have ready access to all their parts*, they do not become wholly converted into carbonate until after the lapse of a very long period of time. In some thick walls 600 years old, the lime has been found to have absorbed only *one-fourth* of the carbonic acid necessary to convert the whole into carbonate; in others, built by the Romans 1800 years ago, the proportion absorbed has not exceeded *three-fourths* of the quantity contained in natural limestones. In damp situations the absorption of carbonic acid proceeds most slowly.

1°. *Change undergone by pure lime during spontaneous slaking.*—In consequence, however, of the strong tendency of caustic lime to absorb carbonic acid, a quantity of the hydrate of lime first formed, when lime is left to slake spontaneously, becomes changed into carbonate during the slaking of the rest. But, when it has all completely fallen, the rapidity of the absorption ceases, and the fine slaked lime consists of—

		per cent.		cwt.
Carbonate of lime		57·4	or,	$11\frac{1}{2}$
Hydrate of lime ...	lime, ... 32·4; water, 10·2	42·6		$8\frac{1}{2}$
		100		20

Thus a large portion of the lime—about one-half—is again converted into carbonate of lime during this mode of slaking.

When left to slake in *large* heaps, the lime in the interior of the heaps will not absorb so much carbonic acid, as is above stated, till after the lapse of a very considerable time. More caustic lime (hydrate) also will be present, if it be left to slake—as is often done for agricultural purposes—in shallow pits, covered with sods to defend it from the air and the rains.

After the lime has attained the state above described, and which is a chemical compound of carbonate with hydrate of lime, the further absorption of carbonic acid from the air proceeds more slowly, and is only completely effected after a comparatively long period of time.

2°. *When slaked in the ordinary way* lime falls to powder, without having absorbed any notable quantity of carbonic acid. Numerous small lumps also remain, which, though covered with a coating of hydrate, have not themselves absorbed any water. The absorption of carbonic acid by this slaked lime is at first very rapid—so that where the full effect of caustic lime upon the soil is required, it ought to be ploughed in as early as possible—but the absorption gradually becomes more slow, a variable proportion of the compound of carbonate and hydrate above described is formed, and even when thinly scattered over a grass field, an entire year or more may pass over without producing the complete conversion of the whole into carbonate. To this state of carbonate, however, it does at length come when long exposed to the air or long mixed with the soil.

The following table exhibits *the chemical changes*

which a ton of limestone undergoes, and the relative proportions in which the several compounds exist in it after it has been burned, slaked, and then exposed to the air or mixed with the soil:—

Composition.	Limestone.	After burning.	After slaking.	Spontaneously slaked.	Exposed to the air or in the soil.
	cwts.	*cwts.*	*cwts.*	*cwts.*	*cwts.*
Lime	11¼	11¼	11¼	11¼	11¼
Carbonic acid...	8¾	—	—	2¾	—
Water	—	—	3½	1¾	8¾
Total weight	20	11¼	14¾	15¾	20

3°. *Calcined or burned magnesia*, whether in the pure state or when mixed with quick-lime, as it is in the magnesian limes, absorbs carbonic acid more slowly than lime does—and by mere exposure to the air may perhaps never return to its original condition of carbonate of magnesia.

When allowed to slake spontaneously, three-fourths of it become ultimately changed into carbonate, and form a compound of hydrate and carbonate which is identical with the common un-calcined magnesia of the shops. This compound consists of—

Carbonate of magnesia	69·37
Hydrate of magnesia	16·03
Water...	14·60
	100

and it undergoes no further change by continued exposure to the air.

But if slaked by the direct application of water, magnesia, like lime, forms a hydrate only, without absorbing any sensible quantity of carbonic acid. The hydrate thus produced is met with in the form of mineral deposits on various parts of the earth's surface, and this mineral is not known to undergo any change, or to absorb carbonic acid though exposed for a great length of time to the air. When magnesian limes are slaked by water, therefore, the magnesia they contain may remain

in whole or in part in the caustic state (that of hydrate), and may change very slowly even when exposed to the air. When left to spontaneous slaking, one-fourth of the magnesia, at least, will always remain in the caustic state, however long it may be exposed to the air. When mixed with a soil containing vegetable matter, it is brought more constantly in contact with carbonic and other acids, and thus more speedily loses its caustic state, but the prolonged presence of this caustic magnesia is one of the causes of the injurious action which magnesian limes exercise upon the land.

Should a lime be naturally of such a kind, or be so mixed with the ingredients of the soil as to form a hydraulic cement or an ordinary mortar, which will solidify when rains come upon it, or when the natural moisture of the soil reaches it—the absorption of carbonic acid, either by the lime or by the magnesia it contains, will in a great measure cease as soon as it becomes solid, and a large proportion of the lime will remain caustic for an indefinite period.

SECTION V.—STATES OF CHEMICAL COMBINATION IN WHICH, AFTER BURNING, LIME MAY BE APPLIED TO THE LAND.

There are, therefore, four distinct states of chemical combination, in which lime, after being burned, may be artificially applied to the land.

1°. *Quick-lime or lime shells*, in which the lime as it comes from the kiln is uncombined either with water or with carbonic acid.

2°. *Slaked lime or hydrate of lime*, in which, by the direct application of water, it has been made to combine with about one-fourth of its weight of water.

In both these states the lime is caustic, and may be properly spoken of as caustic lime.

3°. *Spontaneously slaked lime*, in which one-half of the lime is combined with water and the other half with carbonic acid. In this state it is only half caustic.

4°. *Carbonate of lime*—the state in which it occurs in nature, and into which burned lime, after long exposure to the air, is more or less perfectly converted. In this state lime possesses no caustic or alcaline properties, but is properly called *mild* lime.

5°. Bi-*carbonate of lime* may be adverted to as a fifth state of combination, in which nature often applies lime to the land. In this state it is combined with a double proportion of carbonic acid, and is readily soluble in water (p. 4). Hence springs are often impregnated with it, and the waters that gush from fissures in the limestone rocks spread it through the soil in their neighbourhood, and sweeten the land. In the soil a portion of the lime that has been artificially added is gradually converted into bi-carbonate, and thus is either more generally diffused through the soil or is washed out of it altogether by the frequent rains.

I shall hereafter speak of these several states under the names of *quick*-lime, *hydrate* of lime, *spontaneously slaked* lime, *carbonate* of lime, and *bi-carbonate* of lime. By adhering to these strictly correct names, we shall avoid some of that confusion into which those who have hitherto treated of the use of lime as a manure have unavoidably fallen. The term *mild* applies only to that which is entirely in the state of *carbonate*.

Magnesia, in the magnesian limes, may in like manner be either in the state of *calcined* magnesia, of *hydrate* of magnesia, of *spontaneously slaked*—meaning by this the compound of hydrate with carbonate—of *carbonate*, or of *bi-carbonate* of magnesia, the latter of which is soluble in water to a very considerable extent.

SECTION VI.—OF THE BENEFIT OF BURNING AND SLAKING.

But if lime, as above represented, becomes again changed into carbonate after it has been laid upon the land—nay in part even during the process of slaking—what benefit does the farmer derive from the expensive process of burning and subsequent slaking? The benefits are partly chemical and partly mechanical.

1°. While in the caustic state it acts more quickly in producing those chemical changes which follow from mixing it with the soil. Even in the half-caustic state of spontaneously slaked lime, its effects are more rapid and more quickly seen, than when it is entirely in the state of carbonate.

2°. But the principal benefits arise from the minute state of division into which the lime is brought by burning and slaking. When the burned limestone is slaked, the lime falls to a powder, finer probably than any which could be produced by mere mechanical means—finer certainly than any to which the farmer could bring it, by any crushing machine he could afford to employ. This state of fine powder enables it

a. To be diffused more equably and more universally through the soil, and thus to go much farther in improving it.

b. To combine with acid substances in the soil, and therefore to sweeten it, more readily and more quickly.

c. To come into closer contact with the organic substances in the soil, and thus to promote more fully those chemical changes which are constantly going on in every fertile soil, and to promote which is one of the useful purposes for which lime is added to the land.

It is because of their minuter state of division that fine and dry marls are the most esteemed. The state of fine powder in which it is found, is one reason also why the infusorial sand of the Norman coast (p. 23) is found by the local farmers to be so much better for

their land, and therefore more valuable than the shell-sand, which also abounds on these coasts.

SECTION VII.—OF LIME COMPOSTS, LIME AND SALT, AND THE REFUSE LIME OF THE GAS WORKS.

1°. *Lime composts.*—Quick-lime is often mixed with the roots of weeds, with the cleanings of ditches, with peat, and with the parings of the hedge-sides, and is then laid up in heaps in the form of composts. When mixed in this way the decaying vegetable matter supplies a sufficient quantity of carbonic acid to convert the whole of the lime into carbonate. If these composts are exposed to the air for a considerable time, and especially if they are turned over once or twice, a small quantity of *nitrate* of lime is produced, a compound which is very favourable to the growth of plants. In composts, therefore, the lime exists chiefly in the state of carbonate, a small and variable proportion being in the state of nitrate, and perhaps of sulphate and humate.*

2°. *Lime and salt.*—When common salt and slaked lime are mixed together, the salt is decomposed in whole or in part, and the soda of the salt is brought into the caustic state, while the lime is converted into chloride of calcium.† Both of these are very soluble in water,

* For *humate* of lime, see Chapter III., Section IV.

† *Calcium* is a peculiar white metal, which, when heated in the air, takes fire and burns, combining with the oxygen of the air, and forming *lime*. Lime, therefore, consists of calcium and oxygen.

Sodium is a white metal, which also takes fire and burns when heated in the air, combining with its oxygen, and forming *soda*. Thus soda consists of sodium and oxygen.

Chlorine is a peculiar kind of air, of a greenish yellow colour, which exists in common salt, and forms more than half its weight.

Common salt is a combination of chlorine with sodium, and is called *chloride* of sodium.

and can therefore readily act both upon the soil and upon the plant. Wherever common salt is useful to the soil, this mode of applying it in connection with the lime may be safely recommended. It should be mixed with the lime in such quantity as to allow from 1 to 4 cwts. of salt to be laid upon each imperial acre. The salt may be dissolved in water, and thrown upon the lime where it is the custom to slake it with water, or sea-water may be employed, when it can be readily obtained, without admixture, for slaking the lime.

The Liverpool refuse salt, when well mixed with quicklime, is said to form a powerful dressing for wheat and to benefit the after clover and oats.

3°. *Refuse lime of the gas-works.*—This refuse lime consists of a mixture of carbonate of lime with a variable quantity of gypsum and other salts of lime containing sulphur, and a little coal-tar and free sulphur, the whole coloured usually by a little Prussian blue. The following table exhibits the composition of two gas-limes which have been analysed in my laboratory, the one from the Edinburgh gas-works, and the other from the gas-works in Brick-Lane, London. The first two columns show what they *were* when sent to me, the second two what they *will become* after long exposure to the air, after being made into compost, or after being thoroughly and for a length of time incorporated with the soil :—

When lime and common salt are mixed, the lime gives up its oxygen to the sodium and the common salt its chlorine to the calcium, forming soda and chloride of calcium. The change will perhaps be more intelligible to the reader when represented thus :—

$$\begin{array}{l}\left.\begin{array}{l}\text{Chloride of Sodium,}\\ \text{or Common salt...}\end{array}\right\} =\\ \\ \text{Lime ....} =\end{array}\left\{\begin{array}{l}\left.\begin{array}{l}\text{Chlorine ....}\\ \left.\begin{array}{l}\text{Sodium}\\ \text{Oxygen}\end{array}\right\}\text{Soda}\\ \text{Calcium ....}\end{array}\right\}\text{Chloride of calcium.}\end{array}\right.$$

COMPOSITION OF GAS-LIMES.

	As they are. Edinburgh.	London.	As they will become. Edinburgh.	London.
Water and coal-tar	12·91	9·59	12·91	9·59
Carbonate of lime............	69·04	58·88	67·39	56·41
Hydrate of lime (caustic)	2·49	5·92	——	——
Sulphate of lime (gypsum)	7·33	2·77	16·45	29·32
Sulphite and hyposulphite of lime*.....................	2·28	14·89	——	——
Sulphuret of calcium	0·20	0·36	——	——
Sulphur	1·10	0·92	——	——
Prussian blue..................	2·70	1·80	2·70	1·80
Alumina and oxide of iron	——	3·40	——	3·40
Insoluble matter(sand,&c.)	0·64	1·29	0·64	1·29
	98·69	99·82	100·09	101·81

This table shows that these gas-limes differ much in composition, especially in the proportions of sulphur or of the acids of sulphur they contain. This arises chiefly from the kind of coal which is employed in the manufacture of gas in different works. In Scotland, different varieties of cannel coal are very extensively employed; in London, the better kinds of Newcastle coal are chiefly used, all of which either contain or give off more sulphur than the best cannel coals of Scotland.

The most marked difference between the two samples here analysed is in the compounds called *sulphite* and *hyposulphite* of lime. The latter of these substances dissolves readily in water, and its presence in such very different proportions satisfactorily accounts for the very different effects which have followed from the application of gas lime to the land in different districts. The rains dissolve the hyposulphite and the sulphuret, and carry them down in too great quantity to the roots of the young corn, and hence the complaints of some, that the gas-lime has killed their wheat, while others have found, when applied as a top-dressing in a si-

* This includes a small quantity of cyanide and sulphocyanide of calcium, which are soluble in water, and are present, as all these compounds of sulphur are, in variable quantity.

milar way, that it greatly improved their crops of corn. Unless its composition be satisfactorily ascertained, therefore—unless, for example, it be found that water dissolves very little of it—there will always be a degree of risk in applying it directly to the land while any corn crop is growing. There may not be the same danger in putting it between the turnip or potatoe drills, and afterwards ridging up the land in the way that quick-lime is applied in many districts. To fallow land, however, to land which it is intended to reclaim, and especially to mossy land, the Scotch varieties at least may be applied directly, with safety, and with great benefit. In the neighbourhood of Paisley it is in constant demand for the improved moss lands, and sells at about 1s. 6d. a cart.

But those varieties which contain the largest quantity of the soluble hyposulphite of lime also form at last the largest quantity of gypsum. Thus the Edinburgh lime analysed would never come to contain more than 17 per cent., but the London lime might eventually contain as much as 30 per cent. of gypsum. This suggests the propriety, therefore, of laying it on and harrowing it slightly in some months before any crop is sown—in the spring, for instance, before the turnip sowing—or of making it into composts, perhaps the best and safest method of all.

This lime ought in no case, if possible, to be wasted, and from what has been above stated, it appears that it may always be safely used—

a. Directly upon mossy land, upon naked fallows, and in spring when preparing for the turnips.

b. In composts, in which, by the action of the air, the whole of the soluble salts of lime will have a tendency to be converted into gypsum, and consequently the benefits which result from a large application of gypsum will be obtained by laying such composts upon the land.

c. As it appears usually to contain only a small proportion of caustic lime, it may be with safety mixed at once with the manure, though not in too large quantity. It may also prove a valuable admixture with guano, on which its action will ultimately be to fix rather than to expel the ammonia.

d. Strewed *sparingly* over the young braird, it is said to prevent the attacks of the turnip fly, and harrowed in, in considerable quantity, when the ground is naked, slugs and *wire-worm* disappear before it. The action upon this last pest of the farmer will probably be greatest when the soluble hyposulphite is largest in quantity. If as dry as the specimens of which I have given the analysis above, the gas-lime is worth to the farmer, at least, one-half as much as an equal weight of quick-lime.

If applied in too large quantity in this way, however, it is sometimes injurious to the young corn crop, which has not time to recover from its effects till much of the season of early growth is past. But grass land, though at first browned by the application, soon recovers and repays the cost of application by a greener and earlier bite in spring.

It is at present proposed to mix a quantity of sulphate of soda with the lime in the dry purifiers of the gas-works; should this method be introduced the refuse lime will become of much more value than heretofore as an application to the land.

CHAPTER III.

Is lime indispensable to the fertility of the soil? States in which lime exists in the soil. Quantity of lime which *may* be in the soil. Quantity which *ought* to be in the soil. Theoretical quantity of lime which ought to be added to the soil. Circumstances which modify the quantity that ought to be added. General influence of geological structure on the quantity of lime required. Special influence of the trap rocks on this quantity. Quantity of lime usually added to arable land in different districts.

SECTION I.—IS LIME INDISPENSABLE TO THE FERTILITY OF A SOIL?

The practical farmer in nearly all countries has been accustomed to add lime to the soil; but can lime not be dispensed with? Is there no improved mode of culture by which the use of lime may be superseded? There are several considerations from which an answer may be drawn to this question.

1°. Extensive and prolonged experience has shewn that the fertility of many soils is increased by the regular addition of lime—and that if it be for a series of years withheld, such soils become incapable of producing luxuriant crops.

2°. All *naturally* fertile soils are found upon analysis to contain a notable proportion of lime; while in many of those which are naturally unproductive, the proportion of lime is comparatively small.

3°. A naturally productive soil, even though regularly manured, is often found, after long cropping, to become incapable of growing particular crops in an abundant or healthy manner. On analysis, these soils are not unfrequently found to contain only a very small propor-

tion of lime. After an addition of lime to such soils, it is often observed that the diseased or failing crops grow again healthily and in abundance.

4°. Lime is often added to one part of a farm without producing any visible effect, while upon another it greatly increases the produce. In such cases, a chemical analysis not unfrequently shows that those soils or fields on which it produces no effect already contain a sufficient supply of lime.

Thus barren sandy soils often admit of profitable cultivation after lime has been added—clay soils in which no lime can be detected are often entirely changed by the addition of lime. So, also, it may be laid with profit upon soils formed from decaying granite, while it is frequently thrown away when applied to soils of decayed trap. This is chiefly because the granite contains little lime naturally, while the trap rocks abound in it.

These practical considerations all lead to the conclusion that *lime is really indispensable to the fertility of the soil.*

5°. This conclusion, drawn from experience, is rendered certain by the fact, that all the crops we raise contain lime, which they derive solely from the soil. To this fact I shall more particularly advert in a subsequent chapter when treating of the purposes served by lime in the soil.

SECTION II.—QUANTITY OF LIME WHICH MAY OR OUGHT TO BE PRESENT IN THE SOIL.

It is an exceedingly difficult point to determine the limits within which the proportion of lime in a soil ought to be kept in order to maintain the highest degree of fertility. So much depends upon the proportions of the other ingredients of the soil—upon the quantity of sand, of clay, or of vegetable matter it contains—that the pe-

culiar nature of almost every soil would require to be studied in order to know how much lime it ought to contain, or how much may be safely added to it with the hope of a profitable return. Sandy and peaty soils, when dry, require less than such as are naturally heavy or undrained.

We know that the limits are really very wide within which the proportion of lime in the land may be kept without preventing it from growing good crops. But there are three questions in regard to these limits, to which the practical man is interested in obtaining satisfactory answers. How *much* may be present in the soil, or how *little*, without rendering it unproductive, and what proportion *ought* to be present, in order to make it fertile in the highest degree.

1°. *How* MUCH *may be present?*—I have already alluded (p. 29) to the practice of deep ploughing in the chalk soils of Surrey and the neighbouring counties. When five to seven inches of pure chalk are brought up and mixed with an upper soil only six inches deep, it is obvious that the quantity of carbonate of lime in the mixed soil must be very great. And if these soils so deepened become, under skilful management, more productive than before, it is obvious that the presence of a very large proportion of carbonate of lime will not prevent a soil from yielding good crops.

Through the kindness of Mr. Davis, in sending me a portion of the surface soil of such an improved chalk field, near Croydon, I have been enabled to analyse it, and have found it to contain 41 per cent. of carbonate of lime in the form of crumbled chalk.

The natural soil of the plains of Athens lately sent me for analysis contains also nearly as much lime, as appears in the following results :—

SOIL FROM THE PLAINS OF ATHENS.

Organic matter	5·75
Salts, soluble in water (common salt and sulphate of soda)	0·20
Sulphate of lime (gypsum)	0·18
Oxide of iron	2·91
Alumina (soluble in acids)	2·35
Carbonate of lime	38·08
Carbonate of magnesia	0·73
Phosphate of lime	0·033
Insoluble siliceous matter	50·33
	100·563

This soil *produces excellent crops of wheat*, but is liable when the dry season comes to be covered over with a crust of saline matter which prevents it from growing grass.

2° *How* LITTLE *may be present?*—It is more difficult to say how little lime may be present without materially affecting the fertility of the soil. The nature of the surface and under soil of a field, the circumstances in which the field is placed, and the kind of cropping to which it is subjected, all materially affect this question.

a. If the upper soil abound in vegetable matter the proportion of lime cannot be diminished to so great a degree without affecting its fertility—while if the under soil abound in lime so large a proportion may not be absolutely necessary in the surface.

b. The circumstances in which the field is placed will influence the proportion of lime that is absolutely necessary. Thus, if springs arise in it the waters of which contain lime, or if waters impregnated with lime flow from the adjacent rocks or hills, as in the formation of marl beds (p. 14), or if the yearly rains wash down into it from the higher grounds the lime which they contain—these circumstances may give such a constant supply of lime to the land as to render unnecessary the permanent presence of a large proportion in the soil of the field itself. It is necessary that the effect of such local circumstances

should be, in all cases, taken into account, otherwise analysis might sometimes lead us to suppose, and no doubt has led some to suppose, that a much smaller proportion of lime may be present, without injury to the soil, than is really required—where no such supplies are naturally brought into it—to keep it in an average state of fertility.

Thus, Sprengel found upon analysis, that the rich marsh lands of Holstein and East Friesland contained only a minute proportion of carbonate of lime—the

Marsh lands of Holstein, only ... 0·2 or one-fifth per cent.
The salt marshes of East Friesland 0·6 or three-fifths per cent.

But we should be wrong were we to conclude that because these lands bore rich and fattening pastures, therefore, this small proportion of lime is sufficient to make every land bear good grass. The floodings to which these lands are subject, or the supplies of water that are constantly brought into them from beneath, no doubt contribute, in a considerable degree, to the permanent richness of the grass they bear.

It appears, however, from these analyses that, under certain circumstances, a very small proportion indeed may be sufficient to keep the land in a state of permanent fertility.

c. But something also depends upon the kind of crops we wish or continue to grow. It is possible that grass land may require less lime than arable lands, because the roots of the grasses are small, branch out in every direction so as to come into contact with a large proportion of the soil, and remain in the land the whole year through, collecting their food from the soil. A field of old grass land in the neighbourhood of Durham I found to contain 1·3 per cent. of carbonate of lime.

Yet when such land is ploughed up, though it may give one or more good crops by the aid of the decaying

vegetable matter of the turf, it will soon refuse to grow healthy crops of corn or oats, and certainly large green crops, unless lime be added in greater or less proportion. I have already alluded to the fact that crops become diseased—grow up perhaps well at first, but afterwards assume a sickly appearance, or fail altogether—when the proportion of lime in a soil becomes very small. This is true of every kind of soil in almost every part of the world, and in reference to almost every crop. The first of the following soils was sent to me with the statement that for four rotations the turnips had come up well, but in the autumn had always become diseased, rotted, and failed, and a remedy was asked—on the second, barley came up well, but afterwards failed—on the third plantains refused to grow—

	PINKIE.	LYNEDOCK. Soil.	LYNEDOCK. Subsoil.	JAMAICA.
Organic matter	6·69	10·03	2·05	9·59
Salts soluble in water	1·07	trace	trace	1·16
Oxide of iron	6·91	3·02	5·12	3·21
Alumina		2·56	2·23	1·16
Sulphate of lime	——	0·44	0·14	——
Carbonate of lime	0·31	0·30	0·37	0·38
Carbonate of magnesia	trace	trace	trace	trace
Oxide of manganese	0·24	——	——	0·07
Siliceous matter	84·58	83·37	88·20	84·31
	99·80	99·72	98·11	99·88

In all these soils, and especially in the first and third, the proportion of lime is very small, and though each case required other special remedies also, I recommended, among the measures to be taken with the view of rendering them productive, the addition of lime in one form or another to them all.

I consider, therefore, that these soils contained less than arable land which derives no supply from any natural source *ought* to contain, if it is to produce healthy and abundant crops.

3° *How much* OUGHT *to be present?* To maintain a soil in the highest state of fertility, it is not necessary that it

should contain so much as was found in the chalk and Athenian soils above described (pp. 56 & 57), nor so little as was present on those from Pinkie, Lynedoch, and Jamaica. Those soils which are naturally most fertile, in *all* our cultivated crops, usually contain a considerably larger quantity than was present in these latter soils,—while those which naturally contain so small a proportion are almost universally improved by an addition of lime. Still, scarcely any proportion can be stated which will be really the most advantageous for any considerable number of different soils. As a matter of opinion, however, I may state that I believe there are few soils to which lime, in the proportion of, or in quantity equal to, three per cent. of the carbonate will be too much—while, on the other hand, there are not many in which it will be of advantage to increase the proportion of carbonate beyond from six to ten per cent.—*provided this carbonate be in a sufficiently minute state of division* (see p. 48).

So much, however, as I have already said, depends upon the nature of the soil—its locality, its stiffness, the state of drainage, the proportion of vegetable matter and of oxide of iron it contains,—and upon the state of chemical combination and of mechanical division in which the lime exists in the soil; that I should consider it necessary to enquire into all these circumstances in each special case before I ventured to give a decided opinion, as to the expenditure of lime and money for which a profitable return was likely to be obtained.

SECTION III.—STATES OF CHEMICAL COMBINATION IN WHICH LIME IS KNOWN TO EXIST IN THE SOIL.

This lime which, in certain proportions, is so indispensable to the fertility of the soil may exist in it, however, in various states of chemical combination.

1°. *In the state of carbonate.*—In most of the soils in

chalk and limestone districts, and in those to which lime or marl has been largely or regularly added, a considerable proportion of the lime exists in the state of carbonate (p. 2). The presence of this carbonate is readily detected either by the appearance of white specks in the soil when examined by the aid of the microscope—or by the bubbles of gas which may be seen to arise from it, when vinegar or diluted muriatic acid is poured upon it. By slow degrees, however, it becomes converted in the soil into one or other of the compounds about to be described.

2°. *In the state of bi-carbonate.*—During the decay of the vegetable matter of the soil carbonic acid is formed. This is partly absorbed by the water lodged in or which passes through the soil, and the water thus charged with carbonic acid dissolves, time after time, small quantities of the carbonate of lime which the soil contains and holds it in solution as *bi*-carbonate (p. 4). In this state of bi-carbonate it partly enters into the roots of plants and supplies the lime which they require for their healthy growth, and is partly carried away into the drains or other natural outlets by which the excess of water usually escapes from the land.

3°. *In the state of sulphate of lime, or gypsum,* it exists in minute quantity in nearly all soils. Its presence may be detected by boiling a portion of the soil in water, allowing the water to stand till it becomes clear and then evaporating or boiling down the liquid nearly to dryness. Minute white crystals of gypsum will then form, if any be present in the soil.*

Gypsum is not known—like the carbonate of lime in

* It may be detected with less trouble by taking two separate portions of the water, and dropping into one a solution of chloride of barynm, which will give a white cloud if sulphuric acid be present, and into the other a solution of oxalate of lime, which will give a white cloud, or a slight milkiness, after a time, if lime be present. But this method requires the possession of substances not usually in the hands of practical men.

our chalk soils, or in that of Athens, of which the analysis is given above (p. 57)—ever to form a large proportion of any fertile soil, and it is doubtful, therefore, whether, if it were present in any case in a *very* large proportion, the soil would be likely to produce good crops.

There are many soils, however, in which nearly all the lime they contain is present in the state of sulphate. Such is the case with the following soils from Ayrshire, analysed in my laboratory. They are from the estate of Mr. Campbell, of Craigie, near Ayr :—

SOILS FROM CRAIGIE.

	1.	2.	3.	4.
Organic matter	6·75	9·72	7·17	3·58
Gypsum	0·50	0·64	1·30	0·70
Oxide of iron	2·60	2·42	5·58	3·52
Alumina (soluble)	1·72	0·61	0·95	1·13
Phosphoric acid	trace	trace	0·13	0·08
Carbonate of lime	——	——	——	——
Carbonate of magnesia	trace	trace	trace	trace
Oxide of manganese	0·49	0·22	0·38	0·19
Insoluble siliceous matter	87·30	86·09	83.96	90·09
	99·36	99·70	99·47	99·29

In the state of sulphate, lime can only perform one of the many useful purposes which, as I shall hereafter show, it is fitted to perform. When all the lime is in this state of sulphate an unhealthy condition of the soil is often indicated—the existence or natural production of too large a proportion of sulphuric acid. This production of sulphuric acid takes place more constantly and more extensively in the soils of certain geological formations—and its evil consequences can be most economically guarded against by the practical man by the insertion of drains and by the frequent application of moderate doses of chalk, burned lime, or marl.

I need scarcely add that, where this sulphate already exists in the soil, or where there is a tendency to produce it, less profit is to be expected from the use of

gypsum, either as a top-dressing alone or when applied along with the manure.

4°. *In the state of phosphate,* lime occurs very sparingly in the soil, though there are probably few fertile soils in which it is wholly wanting in this state of combination. In such as have been repeatedly dressed with bones it may be expected in larger proportion, and in such as have not been exhausted by repeated crops of corn or by the long continued practice of rearing young stock. Still, even in an unexhausted or well boned soil, it may be contained in too small a proportion to be capable of being estimated in the quantity of soil usually employed in making an analysis. The determination of this ingredient of a soil, therefore, requires great dexterity and much skill in chemical manipulation.

The mode of detecting it is to digest 500 or 1000 grains of the dry soil in dilute muriatic acid for twelve hours by a gentle heat, to filter and add ammonia (hartshorn), when a reddish brown precipitate will fall. If this precipitate be collected, and vinegar be poured upon it, the whole will dissolve, if no phosphoric acid be present. If any thing remains undissolved, it is phosphate of iron, and from its weight, when collected, the quantity of phosphoric acid, and consequently that of the *phosphate of lime** in the soil may be calculated.

5°. *In the state of silicate,* the quantity of lime contained in the soil is variable, but usually small. In stiff clays it generally forms part of the insoluble portion which remains behind after they have been digested in muriatic acid, and it is often present in the stones and decaying portions of rock which are mingled with nearly all soils. It is especially abundant in fragments of the

* The chemical reader will understand that the phosphoric acid *may* be combined with the oxide of iron in the soil, and not with the lime. Into this point I do not here enter, as in very many cases it must remain a mere matter of opinion with what subtance this acid is combined when it is present in the soil.

trap-rocks, and those of the older slates usually contain it in appreciable quantity. Thus the per-centage of lime in the state of silicate contained in a stiff clay from Derbyshire, in fragments of clay slate from a soil near Wigton, and of trap from a soil near Edinburgh, was as follows :—

	Lime in the state of silicate.
Stiff clay	1·1 per cent.
Decaying slate	0·96 ...
Decaying trap	2·9 ...

When present in the soil in this state, it is only dissolved in part, often in very small part, by digesting the soil in acids. It will often, therefore, escape the notice of the chemist by whom the insoluble part is neglected. And yet if we compare the quantities above given with the whole quantity of lime found in many soils (pp. 59 & 62), we shall be satisfied that the proportion which is present in the state of silicate must often form an important part of the whole lime which a soil contains. And as the proportion of lime, and the state in which it is present, are points which ought to be considered in forming an opinion in regard to the agricultural capabilities of almost every soil, the improvement of which it is susceptible, and the way in which that improvement is to be effected—it must often be of consequence that the quantity of lime, in the insoluble part, should be accurately ascertained. This, however, involves more time and labour and a higher chemistry than the expense which most people are willing to incur will permit the skilful analytical chemist to bestow upon it.

The importance of attending to this insoluble part is remarkably illustrated by the following analysis of a virgin soil, from the site of a portion of the old Caledonian Forest, lately cleared and trenched to a depth of three feet, by Mr. Burnet, of Gadgirth, near Ayr. The portion analysed was taken from a depth of 12 inches :—

SOIL OF THE CALEDONIAN FOREST, AT GADGIRTH.

Organic matter	5·29
Salts of potash and soda	0·43
Gypsum	trace
Carbonate of lime	trace
Lime in the state of silicate	4·15
Carbonate of magnesia	0·51
Oxide of iron	5·81
Alumina soluble in acids	2·05
Alumina in the state of silicate	11·12
Phosphoric acid	0·02
Silica	69·16
	98·54

This soil, analysed in the ordinary way by the action of acids, gave scarcely a trace of lime either in the state of carbonate or of sulphate (gypsum), and yet it contained no less than 4 per cent in the silicate.

This silicate of lime undergoes a gradual decomposition in the soil, and the lime becomes converted chiefly into carbonate, in which state it is probably more directly available for the purposes of vegetation. It is by the action of the carbonic acid contained in the air and in the soil, that this change is brought about, and the decomposition thus effected is supposed to be one of the good results which follow from the prolonged exposure of the soil to the action of the air, where the practice of naked fallows prevails, or where trenching is found to be profitable.

6°. *In the state of chloride of calcium*,* lime exists in

* This name, *chloride of calcium*, requires explanation.

a. Lime consists of oxygen and a metal called *calcium* (p. 49, note).

b. Chlorine is a greenish yellow gas, the colour and smell of which are perceived when a little dry chloride of lime is put into a wine glass and sulphuric acid (oil of vitriol) is poured upon it.

c. Chloride of calcium consists of the metal, calcium, in combination with this gas, chlorine. If chlorine, therefore, take the place of the oxygen in lime, chloride of calcium is produced.

d. Soda consists of oxygen and a metal, *sodium* (p. 49, note).

e. Common salt consists of chlorine and the same metal. It is,

minute proportion in very many soils. In this form it is very soluble in water, and may, therefore, be extracted by boiling a few hundred grains of the soil in half a pint of water, and afterwards evaporating the filtered solution. It rarely happens, however, that one pound of this chloride exists in a thousand pounds of soil. Yet, by the agency of natural causes, it is continually produced in minute quantities in soils which contain much lime in other states of combination, and from its great solubility it is a form in which lime readily finds its way into the roots of plants.

7°. *In the state of humate and ulmate,* lime exists in many soils—but as it is necessary to explain what is meant by the humic and ulmic acids, I shall treat of these combinations of lime in a separate section.

SECTION IV.—OF THE HUMIC AND ULMIC ACIDS AND THE HUMATE AND ULMATE OF LIME.

1°. If the common soda or the pearl ash of the shops be dissolved in water, and boiled upon a quantity of peat broken into small pieces, a dark brown solution will be obtained. If this solution be allowed to settle, and vinegar or diluted muriatic acid (spirit of salt) be then added to it, a brown powder will fall to the bottom. This brown powder consists of humic, with a variable admixture of ulmic acid.

If instead of peat or peaty soil, the ordinary soil of any of our fields be taken, the same dark brown solution and dark brown powder will be obtained, though in smaller proportion. The larger the proportion of vegetable matter in the soil, the larger also, in general,

therefore, called *chloride of sodium.* If its chlorine be exchanged for oxygen, soda will be produced.

Lime and common salt in the soil often mutually exchange their oxygen and chlorine, forming soda and chloride of calcium. The same takes place also to some extent when quick-lime is mixed with salt or is slaked with sea-water (p. 49, note).

the quantity of these acids which a given weight of the soil will yield.

2°. The humic and ulmic acids, and certain other acid substances, are always produced in greater or less quantity during the decay of vegetable matter in the soil. If any substances be present with which they can combine —such as potash, soda, lime, or magnesia—they unite with them and form chemical compounds. But if, as in a mass of peat, such substances are not naturally present in sufficient quantity, those acids accumulate in an uncombined state, and form a sour soil, into which the roots of our cultivated crops cannot safely descend.

3°. When marl or quick lime is added to a soil in which these acids exist, or in which they are gradually produced, the lime unites with the acids, and forms humate and ulmate of lime. Hence, we should expect that a portion of the lime in most soils, and especially in such as abound in vegetable matter, should exist in them in the state of humate or ulmate, and such, upon analysis, is found to be the case.

Few soils have yet been examined with the view of determining how much of the lime they contain is present in this state of humate or ulmate of lime. In some, as in pure peaty soils, we may expect the whole of the lime, soon after it has been applied to them, to be converted into these compounds, while in others a portion of it may long remain in the state of carbonate. Those soils which contain lime in the state of carbonate will effervesce when diluted muriatic acid (spirit of salt) is poured upon them—those which contain only humate will not effervesce, though the acid will dissolve out all the lime.

4°. It is thought by some, erroneously I believe, that the fertility of a soil depends very much upon the quantity of lime it contains in the state of humate. Thus it is stated by M. Dubuc that certain soils in Normandy are very rich in humate of lime, and that these soils also yield the best return of wheat. For example, the soils of—

Locality of soils.	Contain per cent. of Carbonate.	Humate.	And yield of wheat
Lieuvin, Neubourg, and Sistot	—	18 to 20	12 to 15 fold
Pavilli	—	5	8 to 10
Bieville	24	—	8 to 10
Clay of Ouche	—	1	4 to 5

But the large returns yielded by the former two soils are not to be ascribed to the *humate alone*, but to the circumstance that while lime and organic matter in the form of humic acid abound in the soil, it is rich enough also in all the other substances which are necessary to the growth of plants.

This much, however, is to be confessed—that the soil might contain all these other things, and yet be unable to bear good crops were this humic acid present in an uncombined state. The addition or presence of lime, by giving rise to the production of humate of lime, not only does away with the injurious action of this acid upon the roots of plants, but improves also the physical condition of the soil—rendering it less retentive of water, more friable, more open, and more permeable to the air, to water, and to the roots of the growing crops. This is one of the causes of the known good effects which follow from the addition of lime to peaty and other soils that are rich in vegetable matter.

Lime *exists* in the soil in greater or less proportion in all the states of combination described in the present and preceding sections. In the state of quick lime, however, and of carbonate, it is most largely and most extensively *applied* to the land. In what quantity ought lime in those two forms to be applied to our cultivated fields?

SECTION V.—THEORETICAL QUANTITY OF LIME WHICH OUGHT TO BE ADDED TO THE SOIL.

Theory affords us no certain guide as to the quantity of lime which ought to be added to the land. But sup-

pose his soil to be absolutely destitute of lime, then there are several considerations to which it is of importance for the practical man to advert.

1°. The crops which are reaped from an imperial acre of land carry off every year, as part of their substance, as much lime as is nearly equal to *one bushel* of lime shells. So much, therefore, must be added every year to replace what the crops carry off.

But if it is considered that the roots of our corn crops come in contact with only a very small proportion of the soil—not, perhaps, more than one-hundredth of the whole—and that they can draw food only from that part with which they actually come in contact, it will appear that a very much larger quantity of lime ought to be present in the soil, than is merely required by the crop we happen to grow.

Further than this, however, theory cannot go. It cannot fix any absolute quantity which it will be most proper or profitable as a general rule to apply. In fact, as we shall hereafter see, so much must depend upon circumstances, that no absolute quantity can ever be ascertained either by theory or by experience, which will apply to all land or to land in all conditions.

2°. In order *to add one per cent.* of lime to the land, the quantity to be laid on will depend upon the depth. The following table shows the number of tons of burned lime as it comes from the kiln, which will give one per cent. of lime to soils respectively three, six, nine, and twelve inches in depth :—

Tons of burned lime.*	If the depth of the soil be			
	12 in.	9 in.	6 in.	3 in.
	per cent.	*per cent.*	*per cent.*	*per cent.*
16 tons give	1	1½	2	4
12 tons give	¾	1	1½	3
8 tons give	½	¾	1	2
4 tons give	¼	⅜	½	1

* This table is calculated on the supposition that a cubic foot of soil has an average weight of eighty pounds.

The same weights of dry chalk or of shell-sand or limestone gravel or crushed limestone—if unmixed with siliceous or other matter—will add a per-centage of *carbonate* of lime represented by the numbers in the above columns. It must be borne in mind, however, that a ton of this carbonate contains only 11¼ cwts. of well burned lime.

3°. If, as I have stated in a preceding section, as a mere opinion founded upon the results of analyses, three per cent. of lime, at least, ought to be present in a soil which contains an ordinary proportion of vegetable matter and of the other food of plants, then, according to the preceding table, we ought to add to a soil *which is entirely destitute of lime,* as much as

Of quick-lime.

48 tons	when the soil is	12	inches deep.
36	....	9	......
24	....	6	......
12*	....	3	......

These are very large doses, but then there are few soils in which some lime is not already present—and few, therefore, to which the whole of any of these quantities would require to be applied, in order to raise the quantity to three per cent.

But besides the depth of the soil and the quantity of lime already present in it, there are many other circumstances which will modify the quantity of lime it will be proper to apply to the land. I shall consider these circumstances in the following section.

SECTION VI.—CIRCUMSTANCES WHICH MODIFY THE QUANTITY OF LIME THAT OUGHT TO BE ADDED TO THE LAND.

There are many circumstances, as I have said, which will modify the quantity of lime that may most profitably be added to the land. Thus—

* The bushel of lime varies in weight. If we take it at 75 lbs., there are 28 bushels in a ton, and the above weights are equal to 1300, 1000, 650, and 320 bushels respectively. But the bushel varies in weight in different districts.

1°. *The nature of the soil* must be considered.

a. A light sandy soil must not be so heavily limed as a stiff clay. This is familiar to every farmer. Besides those purposes which the lime serves in the lighter soil, it is applied to stiff clays with the view of opening and rendering them more friable and mellow. This of course requires the presence of an additional quantity. In a clay soil also the minute particles of lime are apt to be coated over with a thin layer of impervious clay, which may prevent many of them for a long time from exerting their full effect in promoting the growth of plants. For this reason also a larger proportion is useful. Lastly, lime cannot be diffused through a clay soil so easily or so completely as through a light or sandy soil, and therefore it must be added in larger quantity in order that it may be made equally accessible to the roots of plants.

Hence in the same neighbourhood—as in parts of Renfrewshire, where 2 or 2½ tons are considered enough for the hill side (sharp or gravelly) land, 6 to 8 tons are considered indispensable on the heavy land of the bottoms.

b. Such, again, as are poor in vegetable matter will bear less lime than such as are rich in decaying animals and plants. One of the uses of the lime is to combine with acid substances which are naturally produced during the decay of vegetable matter in the soil—the larger the quantity therefore of the dead roots and other parts of plants, the greater will be the demand for lime to perform this function. Besides, as dead plants afford the food on which new races of plants live, and as lime promotes the decay of the former and the preparation of the food they contain, it must be advantageous to the immediate fertility of the soil to add lime more abundantly when much vegetable or animal matter exists in the soil.

Still all soils, in which vegetable matter abounds, will not bear in an equal degree the application of large

doses of lime. Our dry moorish heaths, covered with a black vegetable mould of a few inches thick, resting on a gravelly subsoil, often give excellent crops of oats, and even turnips and barley when first broken up and limed, but afterwards become too light and open to grow oats and clover successfully. To such soils lime should not be added too lavishly, and means should be taken by deep ploughing or otherwise to mix up and solidify the surface soil, that it may contain on the whole a smaller per-centage of organic matter than the few inches at the top usually do in their natural state.

2°. *The state of the soil* is also of great consequence. If the land be wet and undrained a larger dose of lime must be laid on. The moisture, like the coating of clay above referred to, shuts out the air, and prevents the lime from having its full effect. The coldness of such soils also checks the decomposing action of the lime upon the soil, and causes the production of a larger proportion of acid matter—for both of which reasons more lime is required. Further, in wet land a portion of the lime not unfrequently forms insoluble compounds—mortars, silicates, &c.—which do not act in the usual way in benefitting the crops, and thus also larger applications are rendered necessary.

If the soil be a stiff clay as well as full of water, then larger doses still will be required,* and if it be also marshy, and therefore abound in vegetable matter, very large applications of lime must be laid on, in order to obtain the full benefits it is capable of producing.

3°. *The kind of cropping* is also of consequence. Green crops are benefitted by larger doses of lime than

* An instance is mentioned in the Nottingham report of 720 bushels an acre being laid on clay land without any benefit whatever.—*Brit. Husbandry, I., p.* 296. It is possible, however, that besides being undrained, this land might already contain a sufficient *natural* supply of lime. Mr. Stephens says, he has seen 510 bushels applied to wheat land with manifest advantage.—*Book of the Farm, III., p. 996.*

crops of corn. In reclaiming boggy land it has been observed that while the addition of above a certain quantity of lime lessened the after-crop of oats, a turnip or potatoe crop, if taken first, was excellent in proportion to the quantity of lime applied. A similar remark applies to the ploughing up of lea. If corn is to be taken, the liming may be postponed, but, for a green crop, lime will generally be advantageous. By land which is lying in grass, less lime will generally be required in the same number of years, than by an equal extent in arable culture. Much, however, will depend upon the way in which the grass land is treated; and if it is cut for hay, more of course of every thing, and of lime among the rest, will be required than when it is kept in permanent pasture.

4°. *The kind of husbandry followed.*—An improving husbandry, for example, will call for larger applications of lime. If, as a means of improvement, the land be ploughed deeper, the lime will be diffused through a greater body of soil, and should therefore be present in greater quantity. Or if the land be drained and subsoil ploughed, with the view of removing noxious matters from the deeper soil, and of allowing the roots to descend, a more abundant liming may in the first instance be required—since it is desirable that some of it should find its way into the under soil to aid in preparing it for the safe descent of the roots of the growing crops.

5°. *The form in which the lime, already present, exists in the soil* is also a matter of much importance. The soil may contain 6 or even 10 per cent. of lime in the state of silicate and yet pay for the addition of a considerable first dose of *quick* lime, because this silicate must itself undergo decomposition through the joint action of air and moisture before it can produce the usual good effects which follow from the use of lime. A reasonable per-centage of gypsum may also be pre-

sent, and yet the land may pay for liming, because the gypsum is not fitted *directly* to perform *all* the functions of quick-lime or of carbonate of lime in the soil. In this latter case, however, much will depend on the nature of the soil itself, on the kind of manure applied to it, and on the circumstances in which it is placed—points to which I may hereafter have an opportunity of adverting.

6°. *If the land has been previously limed*, a larger quantity is believed to be necessary to produce an equal *sensible* effect. This may arise from several causes.

a. If the land be nearly destitute of lime, when the first application is made, a remarkable effect will necessarily be produced, since a certain proportion is necessary to the ordinary fertility of the land.

On a second or third application, the land already contains more lime than at first, and therefore a larger quantity must be added if it is to come in contact with as many particles of soil on which it can act, as the first lime readily reached.

b. Thus the whole quantity of vegetable matter in the soil, or the quantity of that kind upon which it can readily act, may be less, and thus the lime must be diffused through it in larger proportion if it is to be brought in contact with as much of this vegetable matter, and produce as great a sensible effect.*

c. But the good farmer will not often expect to see upon his old-cultivated land a sensible effect produced by lime equal to that which is seen when it is newly brought into arable cultivation. The addition of lime from time to time, in good husbandry, being made rather to *keep up* the existing condition of a productive soil, than to add materially to its actual fertility. This point will be more fully discussed in the following chapter.

* Another reason applicable to some soils is stated in p. 80.

7°. *The geological character and structure of a country* have also much influence upon the quantity of lime which its soils require, but this point is of so much interest and importance that it will be better to consider it in a separate section.

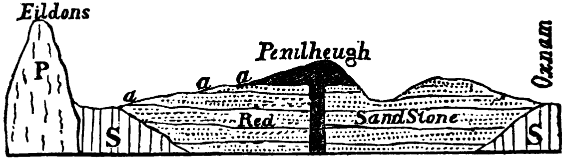
SECTION VII.—GENERAL INFLUENCE OF THE GEOLOGICAL STRUCTURE OF A COUNTRY ON THE QUANTITY OF LIME WHICH ITS SOILS REQUIRE.

Of all the circumstances by which the application of lime is modified—the quantity to be added at once, and the frequency with which it should be repeated—there is none of so great and so general an importance, and at the same time so little understood by the practical man, as that of the geological structure of the district in which he lives.

1°. Our soils are formed from the crumbled fragments either of the rocks on which they immediately lie, or of other rocks usually at no great distance. The soils, therefore, must consist very nearly of the same substances as the rocks themselves from which they have been formed. At all events they cannot contain what is not present in the rocks, nor any thing, for the most part, in very large quantity, which is present in the rocks only in very small quantity.

2°. Now the rocks themselves differ very much from each other in different parts of the country. They differ especially in the quantity of lime they contain. Some consist almost entirely of lime—such are the chalk rocks, the cliffs of mountain limestone and the beds of magnesian limestone. Others, like our sandstones and granites, contain comparatively little lime, while in our trap-rocks of various kinds a considerable proportion of lime is almost invariably present.

Hence in a tract of country like that which is represented in the following section :—



where, in travelling from the Eildon Hills, which consist of a felspar porphyry (P), we pass over a slate country (S) to the red sandstone *a, a, a,* then over a considerable extent of trap, at the summit of Penilheugh, to the red sandstone, and finally to the slate country again about Oxnam ;—in such a district as this, where we have four leading diversities of soil formed from as many different kinds of rock, in each of which the general proportion of lime is different from that contained in all the others, the importance and effects of lime, and the necessity for its application, must vary very much.

3°. There are three several ways in which the presence of lime in the original rock affects the quantity of lime contained in the soil which is formed from it. Thus

a. The part of the rock which crumbles down and forms the soil, imparts to it all the lime itself contains. Thus the original soil contains exactly the same proportion of lime as the original rock.

b. But lime, as we have already seen, is soluble in water under certain circumstances. Hence the waters that rise in springs, or which flow from between the beds of rock—as at *a, a, a,* in the preceding section—bring lime with them from the body of the rock itself, and impart it to the soil through which the waters are diffused. Thus this soil becomes or continues richer in lime than it otherwise would be.

The springs that gush out, often very copiously, from

among the mountain limestone hills are generally charged with lime in a high degree. This is indicated by the luxuriant water-cress which lines the bottoms and sides of the streams, and I have often thought among the Yorkshire hills how valuable these streams might be made to the district, if they were employed in irrigating the pasture lands of the sloping vallies through which they so often flow.

c. A more general and permanent effect, however, is produced by the fragments of undecayed and decaying rocks which are mingled with the soil. These stones, upon land which is kept in arable culture, are often stirred up by the plough, and are thus exposed to the air and moisture. They undergo, therefore, a constant slow decomposition, and are continually yielding to the soil small portions of the different substances of which they consist. If they contain much lime, they yield a proportionably larger quantity of this substance to aid the growth of plants. If they contain little, the artificial application of lime will be required more frequently perhaps and in larger quantity.

4°. *The granites and felspar porphyries* usually contain very little lime, and this is the case also with many of the sandstone rocks.

5°. *The mica slates* are also poor in lime. Some subordinate members of this series—the talc slates—are rich in magnesia.

6°. *The clay slates* appear to contain in general but little lime. In a variety from Wexford, analysed by Mr. Antisell, six per cent. of carbonate of lime were found. This is, I believe, an exception to the general rule.

7°. *The slate rocks of the Silurian system* vary much in composition—such as I have examined contain only about one per cent. of lime. To soils formed from such rocks the addition of lime is indispensable, if they are to be brought into a state of profitable and permanent fertility.

8°. *The trap rocks* usually contain much lime, and they are very abundant in Scotland. I shall further illustrate, therefore, the importance of a little geological knowledge to the practical agriculturist, by a special reference to the case of these rocks.

SECTION VIII.—SPECIAL INFLUENCE OF THE TRAP-ROCKS UPON THE QUANTITY OF LIME REQUIRED BY THE LAND.

The trap-rocks do not cover a large portion of the surface of England—but they stretch in a broad but interrupted zone across the whole of the low country of Scotland—covering much of the several counties which lie between the Friths of Tay and Forth on the one hand, and the Frith of Clyde and the bay of Ayr on the other. They are spread also over a large surface in the north of Ireland. The soils upon all this extensive space are formed more or less exclusively of the decayed fragments of these trap or whinstone rocks, and consequently either do now, or have originally, contained a large proportion of lime.

In order to ascertain correctly to what extent the opinion I had formerly expressed* in regard to the agricultural and economical importance of the lime contained in the trap-rocks was well founded, I collected a number of specimens from different localities, and caused them to be analysed in my laboratory. They were all found to contain lime in three different states:

a. In that of carbonate, either originally so existing in them, or formed by the decomposition of the silicate through the action of the carbonic acid of the atmosphere.

b. In that of soluble silicate.—In this state it no doubt exists in the form of some of those numerous minerals

* See *Lectures on Agricultural Chemistry and Geology*, p. 385.

usually called zeolitic by mineralogists, and which are for the most part soluble in muriatic acid.

c. In that of insoluble silicate.—This portion remains behind among the other insoluble matter, after the powdered trap has been digested in hot concentrated muriatic acid.

The following table shows the proportions of lime in each of these states contained in the different specimens of trap which were examined, and also the whole percentage of lime and its equivalent in the state of carbonate :—

QUANTITY OF LIME CONTAINED IN ONE HUNDRED POUNDS OF DIFFERENT VARIETIES OF TRAP.

Locality.	Lime in state of carbonate.	Lime in state of silicate.		Total lime in the trap.	
		soluble.	insoluble.	caustic.	carbonate
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*
Balcarres Hill, Fife (recent)............	0·8	4·26	5·75	10·81	19·21
Pentland Hill, near Swanston (decaying)	8·2	0·12	2·78	11·10	19·75]
SalisburyCrags (recent)	3·02	2·18	2·48	7·68	13·64
Ditto (decomposed)	0·72	0·71	0·91	2·34	4·16
Rothsay (decayed)	0·68	0·51	6·85	8·04	14·22

Several facts are strikingly presented in this table—

1°. That some of the traps contain as much lime as is equivalent to one-fifth of their own weight of carbonate. Such among those in the table are those of Balcarres and the Pentlands—of which every 500 lbs. contain as much lime as is present in 100 lbs. of pure limestone.

2°. That in others the proportion of lime does not exceed two-thirds of this quantity. This of course will materially affect their agricultural value.

3°. That the quantity contained in such as have been partially decomposed is less than in the same variety in a recent state. This is what we should expect from the known action of the rains and other causes, in washing lime from rocks and soils.

4°. That in some, as in those of the Pentland Hills

and of the Salisbury Crags, the proportion of lime in the state of carbonate is very much greater than in others. This arises in great part from their originally containing more in this state, since most of the whin-stones effervesce with acids when quite fresh and newly broken from the parent rock. Still in such as have been long exposed to the air, and have begun to crumble, a portion of the carbonate may be derived from decomposed silicate.

It is obvious, therefore, that the original presence of so much lime in our trap-rock soils must materially modify both the quantity which will require to be added to them, and the frequency with which it must be repeated.

There are four important practical points which, among others, are explained by a knowledge of the presence of this lime:—

1°. We have already seen that decayed trap contains less lime than such as is recent or undecayed. The same is the case with the surface of a trap-soil. We shall by and bye see, indeed, that the upper portion of nearly all soils is gradually deprived of lime by the agency of natural causes.

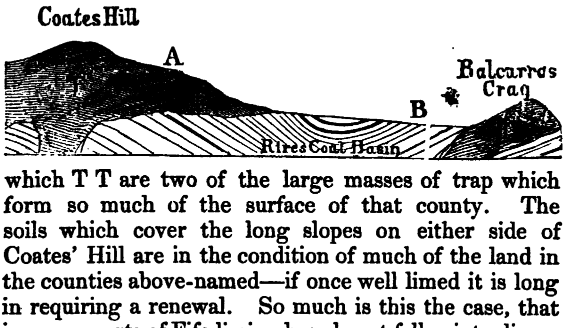
If therefore a trap-soil remains long in an unimproved state, or even very long in pasture, it will, when broken up, exhibit as great an improvement from the addition of lime as almost any other land in similar circumstances. But when the ordinary period arrives at which it is usual to renew the application of lime to other kinds of land, it will often be found that the second dose of lime has little apparent effect on the productiveness of the soil. This effect arises from the circumstances—

a. That when first broken up most of the lime which existed near the surface in the state of carbonate had been washed out, and though there might exist many fragments of undecayed trap in the soil, yet they were not exposed to the air in such a way as to admit of

their being rapidly decomposed. When broken up, therefore, a dose of lime was required to produce those immediate effects which, in reclaiming land, this substance is fitted to produce, But

b. After it was brought into arable culture the turning up of the soil exposed those fragments of rock to the air, and thus caused them to decompose, and, year by year, to yield a portion of carbonate of lime to the land. The effect of this must obviously be, to retard the natural exhaustion of the lime and to put off the period when a new dose of lime may be profitably given.

The counties of Renfrew, Fife, and Ayr present many illustrations of this fact. The following section represents a portion of the south-eastern portion of Fife, in



which T T are two of the large masses of trap which form so much of the surface of that county. The soils which cover the long slopes on either side of Coates' Hill are in the condition of much of the land in the counties above-named—if once well limed it is long in requiring a renewal. So much is this the case, that in many parts of Fife liming has almost fallen into disuse —from the persuasion, on the part of the farmers that, though it did much good to the land in their fathers' time, it now does no benefit to them.

2°. Apparent contradictions in practical experience are reconciled by it. I lately attended a meeting of the St. Quivox Farmers' Club, held at Ayr, at which the subject of conversation was the use of lime. Among the fifty intelligent men who were then present, a considerable number declared, from their own experience,

that lime was of no use to the land whatever, while as many others pronounced it to be a most useful and profitable application—and one large farmer stated that he had been laying it on his land at an expense of several hundred pounds a year, and was so well satisfied with his returns that he meant to continue the practice.

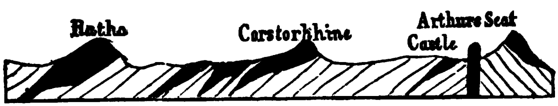
In the patches of trap scattered over its surface, the county of Ayr resembles the county of Fife. Suppose two farmers, situated respectively at A and B on the preceding section—one on a trap soil and the other on the stiff and cold clays of the coal-measures—and suppose an equal time to have elapsed since lime was laid upon the two farms. The tenant at A applies lime, and he finds his money apparently thrown away. The tenant at B lays it on at the same time, and his crops are greatly improved. If these men meet in a club they will each give correct opinions as far as their experience goes, and yet the experience of the one will contradict that of the other. But the natural difference of the soils being understood, the cause of the seeming contradiction, and of the unlike results obtained by different persons becomes apparent. It is clear also, that though a trap soil requires less lime in a given number of years, and is therefore less costly to work on the whole, yet that the greater number of such soils will require occasional liming, especially if laid down to grass, so that even upon them a time will always arrive when it will not appear to be thrown away.

3°. An important agricultural fact in connection with these trap-rocks is, that they are the means of giving lime to the soils which lie beyond their own limits. This I have in some measure illustrated in speaking of the origin of marl beds (p. 13). The rains and springs bring down lime from the trap-soils to those which adjoin them, and which, as in the part of Fife to which I have already alluded, may be naturally of a very different character. The heavy rains wash even the finer parts of

the soil itself down the slopes of the trap hills, and thus fertilize the vallies or flats below. Hence in a district such as the neighbourhood of Edinburgh, over which, though not entirely covering it, the outbursts of trap are very frequent, the advantage of liming, so long as they are kept in arable culture, may be rarely experienced upon any of its farms. The trap soils themselves derive lime from the decaying fragments of rock which are mixed with them, while the adjoining soils are enriched with lime from the washings of the trap soils around them.

The general experience, I believe, of practical men in the neighbourhood of Edinburgh is expressed in a remark once made to me by the late Mr. Oliver, of Lochend, "that he had never known an instance in which the application of lime had done any good within five miles of Edinburgh." I have no doubt that Mr. Oliver's remark was substantially correct, and the main cause of the result he referred to, is distinctly seen in the geological structure of the country,

I have already given in a previous chapter (p. 14) a section of a portion of the immediate vicinity of Edinburgh, shewing the relative positions of some of the most remarkable of the trap rocks near that city—but the prevalence of these rocks over the whole of this part of the Lothians is so strikingly shown in a section given by Mr. Maclaren, in his Geology of the Lothians, that I am certain I shall gratify my readers by inserting a part of it here.



The shaded spots in this section are all trap rocks, and they cover a considerable proportion of the entire surface of the country. But the hollows between the shaded portions will be benefitted by the washings from the trap above, and where the space uncovered by the

trap is comparatively narrow, as between Corstorphine and Ratho, the necessity for lime may be less urgent than where the distance from hill to hill is greater as between the Castle rock and the Corstorphine hills.

4°. This section illustrates also a fact which has frequently puzzled practical men, that lime is some times more required, and produces a greater effect on one side of a hill than on another. The slopes of the Corstorphine hills towards Ratho will obviously derive more benefit from the constituents of the adjacent trap rocks than the plains that lie towards Edinburgh, and the same remark applies to many other localities of a similar kind, and even to hills, which like those of the mountain lime-stone belong to a different geological formation.

SECTION IX.—OF THE QUANTITY OF LIME USUALLY ADDED TO ARABLE LAND IN DIFFERENT DISTRICTS.

Many circumstances, as above shown, must modify the quantity of lime it will be most profitable to add to the land. It is of importance to the practical man to know, however, what are the quantities of quick-lime actually applied to land kept in arable culture—where the benefit of adding lime has been proved by experience. The following table exhibits the proportions usually added in some of the best cultivated districts in the island compared with the custom in Flanders:—

QUANTITY OF QUICK-LIME APPLIED PER IMPERIAL ACRE IN DIFFERENT DISTRICTS.

	Bush.		Years.	Bushels a year.	When applied.
Roxburgh ……	200	every	19	or 10½	to the fallow.
Ayr (Kyle)……	40	…	5	or 8	do., or lea.
Carse of Stirling	54	…	6	or 9	do.
South Durham	90	…	12	or 8½	do.
Worcester ……	70	…	6 or 8	or 10	before grasses & tares.*
Flanders………	50	…	12	or 4	
	12	…	3		

* This is the practice on the stiff clays near the Malvern Hills. The rotation there followed is—1°. Naked fallow; 2°. Barley (for-

The quantity applied in this country appears, from the above table, to be pretty uniformly at the rate of from 8 to 10 bushels a year, except on stiff and imperfectly drained clays, like those of the vale of Gloucester. Some apply it in larger doses and at longer intervals than others, but the average quantity added to dry land of medium quality is on the whole very nearly the same. Of course, in too many cases the expense of the application prevents the tenant-farmer from laying on a sufficient supply.*

In Flanders, again, and in parts of France, the proportion added is less, being on an average not more than half the quantity laid on in this country. The lightness of the soils in Flanders, and perhaps also the climate and the care with which all other kinds of manure are collected and preserved, may in some measure account for this diversity.

The above mode of reckoning by bushels, however, is very uncertain, because of the unlike weight per bushel of different varieties of lime as it comes from the kiln. In the neighbourhood of Alnwick, the bushel weighs from 75 to 80 lbs., while the bushel of Malvern lime is reckoned at 45 lbs., little more than one-half as much. The application of an equal number of *bushels* in these two districts lays very unlike weights of lime upon the land. Such application should always be made by weight.

merly wheat) and a few turnips ; 3°. Clover or seeds ; 4°. Wheat; 5°. Beans, peas, or oats ; 6. Vetches (soiled) with manure, followed by naked fallow. This rotation is certainly not the best, though it may be an improvement on the old four-course of wheat, beans, wheat, and fallow. The quantity of lime applied is stated to me by a correspondent to be from 90 to 100 bushels in eight years ; but as the bushel weighs only 45 lbs. I have halved this quantity in the table given in the text.

* The converse also is often the case where lime is cheap. Thus in the poor, cold, undrained land immediately south of Durham, —where the rotation is fallow, wheat, oats, or fallow, wheat, oats, hay—it is customary either to lime or manure every fallow,

SECTION X.—INFLUENCE OF THE GEOLOGICAL STRUCTURE OF THE COUNTRY ON THE KIND OF LIME WHICH OUGHT TO BE ADDED TO THE LAND.

The *quality* of the lime he applies is of little less moment to the practical man than its quantity. In most districts in which different qualities of lime are to be procured, with nearly equal ease, the farmer selects that which he has found—or which he believes—to be the best adapted for his particular soil.

1°. Thus, of the Irish limes brought by sea and used in Ayrshire, the Drogheda—a blue lime which burns to a light grey or ash-colour—is considered best for general purposes, but particularly for heavy soils. The Cork and Dublin limes which are darker in colour, are also good for stiff land, but are considered inferior to the Drogheda—while the white lime (chalk) from the county Antrim, is superior to either for the lighter soils. These different qualities arise chiefly from the different proportions of earthy matter which the limes contain, and the different degrees of fineness to which they fall when burned and slaked. The Antrim lime falls to an exceedingly fine powder, and is thus better adapted to the more open and loamy soils.

2°. But the most important difference which exists among those varieties of lime that are usually applied to the land is in the proportion of magnesia they contain. This, as we have already seen (p. 38), is often very great.

But in addition to what was formerly stated in regard to the absolute quantity of magnesia contained in certain limestones, it is of importance to the practical man

usually to lime once in six years. The quantity applied is about four double loads—between four and five tons—to the imperial acre; or 20 to 25 bushels of 80 lbs. each year. The tenant is not to blame for this profuse liming. The landlord, who refuses to let his farms for a longer term than six years, is punished by the more speedy exhaustion of his land. These poor lands would become rich under a longer tenure and a more liberal management.

to know that limestones from the same locality often vary much in this respect.

Thus in the same quarry, on the farm of South Whinny Hall, near Burnt Island, in Fifeshire, three different beds are worked, which, according to analyses made in my laboratory, consist respectively of

	Upper Bed.	Middle Bed.	Lower Bed.
Carbonate of lime	86·07	57·18	89·84
Carbonate of magnesia......	9·53	32·90	3·02
Alumina and oxide of iron	3·11	8·62	1·42
Siliceous matter and clay...	1·25	1·18	5·69
	99·96	99·88	99·97

The difference in chemical composition of these three varieties is such as materially to alter the quality and value of the addition made to the soil, according as the one or the other variety is used.

a. Now, among the rocks from which soils are formed there are some which abound in magnesia, and others in which it is found in comparatively small proportions. Thus, the magnesian limestone rocks usually contain much magnesia, as their name implies. To soils formed from this rock, when lime becomes necessary, it should be safer, according to theory, to add a lime in which magnesia is less abundant, and experience proves this to be really the case.

b. So among the beds of the mica slate series those to which the name of talc slates is given contain much magnesia. A fragment of such slate from Banffshire lately analysed in my laboratory, by Mr. Fromberg, was found to consist of

Oxide of iron and alumina soluble in acid	13·83
Alumina, with a little oxide of iron, insoluble in acid...	20·21
Lime	1·44
Magnesia	4·08
Potash and soda	7·28
Silica	52·65
	99·49

Such slates as this will form stiff retentive soils in which lime will be deficient, while magnesia will be present in comparative abundance. In liming this land, therefore, regard should be had to the composition of the lime—and a variety, should be selected, in which the quantity of magnesia present is comparatively small.

c. Other soils again occur—such as those which are formed by the decay of the felspar rocks—in which magnesia is deficient, and to which, therefore, experience may have shown that it is more profitable to apply a kind of lime in which magnesia exists in larger proportion.

Numerous soils have been submitted to analysis in my laboratory, in which magnesia has been found in sufficient abundance, while lime was greatly deficient, and in regard to the treatment of which I have had occasion to recommend the application of heavy doses of lime, with this caution, that those varieties should be selected in which little magnesia was contained.

The consideration of all these facts shows how important, in reference even to practical purposes, a knowledge of the geological structure of a country is,—how necessary that the general constitution of the soil should be ascertained—*and that neither lime nor any other substance should be applied to it of which the chemical composition is not exactly known.*

CHAPTER IV.

When ought lime to be applied to the land? Effect of circumstances on the time of application. Ought lime to be applied in large doses at distant intervals, or in smaller quantities more frequently repeated? Comparative profit of the two modes. Influence of tenure on the mode of applying lime. Mode of compensating for lime laid on by a way-going tenant.

SECTION I.—WHEN OUGHT LIME TO BE APPLIED TO THE LAND?

This question may refer to the period either of the year or of the rotation at which the lime ought to be applied.

1°. *The period of the year* at which *quick* lime is usually applied depends very much upon two considerations of an economical kind.

a. Upon the leisure which the farmer possesses from the other operations of the farm. He does first that which is indispensable. His ploughing, and sowing, and reaping, cannot be delayed. He sends his teams to the lime kiln only when they are at liberty from other operations. Thus the winter months, and those of spring after the corn is sown, are the periods during which, with his own horses, he can most conveniently bring lime to his farm. By some it is then applied as soon as it is slaked, while others lay it up in heaps, and leave it for a time carefully covered with sods. By protecting it from the weather the application may thus be delayed for two or three months, without materially affecting its usefulness to the soil.

b. Upon the period of the year when lime can readily be obtained. In some districts the demand for lime at particular seasons is so great, that the lime-burners within a reasonable distance cannot prepare a sufficient supply. This necessarily retards the operations upon some farms, and causes an alteration in the period when it is most economical to apply it.

In other districts, again, where sea-borne lime is principally employed—the north-east and south-west coasts of Scotland for example—the summer months being the most favourable for transporting the lime by sea, are those also in which the farmer can most readily obtain it. Thus the leisure of his teams is less consulted than the convenience of the sea traffic, and the application of *quick* lime is necessarily made either late in spring, when preparing the land for the turnip and potatoe crop—or in summer, when in some districts it is dusted over the root crops before hoeing or ridging them up—or late in the autumn, when it is spread over the stubble and ploughed in, or over the lea, preparatory to its being brought again into arable culture.

These circumstances of course—though they affect the time of bringing the lime to the farm—do not affect the season of applying it, when it is to be laid on in the compost form. This compost can be made at any season, can remain for any length of time, and can be applied whenever the farmer, from having leisure or for other reasons, considers it most expedient.

2°. But *the period of the rotation*, at which the lime ought to be applied, is of much more consequence, inasmuch as that point being settled, the season of the year at which it will be most proper to lay it on, will also be in a great measure determined.

Now the nature and condition of the land determines the kind of cropping, this, again, the kind of rotation which on the whole will be the most profitable, and the

kind of rotation the period at which the lime ought to be applied.

Thus on heavy soils, where a naked fallow forms part of the rotation, as on the Oxford or Gloucester clays, where wheat, beans, and fallow is the course of cropping—or, as in some parts of Worcester, where the more scourging course of wheat, beans, wheat, fallow prevails—the most natural time for applying the lime is upon the naked fallow.

Again, in an improved rotation upon these heavy soils, where, in consequence of partial draining—as by thorn drains—the naked fallow is resorted to only once in six or seven years, and yet turnips are but little grown, the practice of liming the fallow is not so universally approved. It is applied before the barley to help the seeds, or in the autumn or spring, to help the beans, or clover, or tares, almost as often as to the naked fallow. There is, indeed, no rule or principle, I believe, by which the pecuniary benefit of applying it at the one time rather than the other, can be shown to be distinctly greater.

But where the alternate husbandry prevails—to the exclusion, more or less total, of naked fallows—there are one or two facts which serve as good guides to the practical man, and influence him much in applying his lime. Thus—

a. Lime is found to produce little apparent benefit, upon the first, in some cases even upon the second corn crop after it is applied— there is less inducement, therefore, to lay it on the land immediately before such a crop is to be grown.

b. But the first green or root crop, which follows the application of lime, is almost always benefitted by it. Turnips, clover, tares, and potatoes, show an immediate improvement; and hence the practical man is most frequently induced to apply it when preparing his land for these crops. This determines also, in some

measure, the season of the year at which it should be laid on. In the case of turnips or potatoes, it does not do so absolutely, since some prefer laying it on in the autumn upon the stubble, and ploughing it in with a light furrow—while others incorporate it with the soil in early summer, when ploughing and harrowing and ridging up the land—and some even scatter it over the surface when the turnips and potatoes are already considerably advanced, and are ready for earthing up. In *most cases*, where the lime can be seasonably obtained, I would prefer to harrow it in early in the spring or summer, as likely to keep it nearer the surface of the land, while at the same time it would have been sufficiently intermixed with the soil to prevent its having any injurious effect upon the manure to be afterwards applied. In the case of potatoes, however, it is considered the best practice by the skilful potatoe growers of Renfrewshire, to strew it over the land when the crop is already some way above the ground, and to mix it with the soil in the hoeing. To this practice there appears no objection—it keeps the lime near the surface and prevents it from coming in contact with the manure.

Lastly, where land is to be reclaimed or broken up, from old, sour, matted grass, or from heath, the lime should be applied one or two years before the plough is put into it. By this means the coarse grasses and heaths are destroyed, their roots die and lose their tenacity, and thus to plough it up is a lighter labour, while the land also crumbles and mellows with less working, and the sod disappears in a much shorter period of time. The application of lime for this purpose may be made at any season of the year when the other labours of the farm leave leisure for the purpose. If the grass to be broken up be of value to the farmer, he will of course, in so far as he can, allow that season to

pass over during which its worth for the pasturing of cattle is considered the greatest.

On this point I add only one other observation. *Quick*-lime has the effect of disengaging and setting free the ammonia from guano and from fermenting manures. It is a prudent, therefore, and a safer practice to apply the lime some short time before or after such manures have been laid upon the land. Where the soil is moist and abounds in vegetable matter, there may not be much loss should the lime and other manures come in contact beneath its surface—but in dry soils, and on the surface of the land, the admixture of the two ought to be carefully avoided. After the lime has been some time in or on the surface of the soil and has become converted into carbonate (p. 45), it can exercise no injurious effect upon any kind of manure.

SECTION II.—OUGHT LIME TO BE APPLIED IN LARGE DOSES AT DISTANT INTERVALS OR IN SMALL DOSES FREQUENTLY REPEATED?

This also is an important practical question—in regard to which working farmers differ much in opinion —though it is one upon which in the abstract, it is not difficult to decide. Thus:

1°. A certain proportion of lime is indispensable in our climate to the production of the greatest possible fertility. Let us suppose a soil to be wholly destitute of lime—the first step of the improver would be to add to it this indispensable proportion. This would necessarily be a large quantity, and, therefore, *to land limed for the first time theory indicates the propriety of adding a large dose.*

2°. The full effects of this large dose are not experienced for several years. After the lapse of five or six years during which it has been gradually mixing

with the soil, its beneficial effects become the most striking. *For six or eight years therefore after a heavy liming, no further addition of lime requires to be made.*

3°. But after this period the productiveness of the land, if the treatment continue the same, gradually diminishes—the effect of the lime wears off, and by degrees, if no more be added, the land will return to a condition very nearly the same as that in which it lay before the lime was added. This arises from the circumstance that the lime is gradually removed from the land by the agency of natural causes. *To keep land in the most productive condition, therefore, as much lime ought to be added from time to time as will supply this natural waste.*

4°. We have seen in a previous section (p. 84) that the quantity, which long practice in various districts seems to sanction as necessary to supply this natural waste, is from 8 to 10 bushels a year. After land, which has been once heavily limed, therefore, has reached its most productive condition, *it ought to be supplied at shorter intervals with smaller doses at the rate of about* 8 *bushels a year, in order to keep up its productiveness at a maximum.*

The reader will understand that this repetition of lime is to be recommended only where the land is otherwise well farmed and manured, and where the object is not to take as much as possible out of the land in a given time—but *to retain the land permanently in the most productive condition.*

SECTION III.—COMPARATIVE PROFIT OF THE TWO METHODS.

The superior profit of this latter method of frequent liming is easily illustrated.

Let us suppose that to each of two separate acres of

the same clay land 200 bushels of lime have been applied at the same time. The whole will have been fully mixed with the soil, and will have begun to produce its greatest effect by the end of four or five years. Suppose the crops now to equal 30 bushels of wheat an acre, or the equivalent of this quantity in other crops—and let the one be cropped for 20 years in succession, without any further liming, while the other receives a small dose of 40 or 50 bushels of lime at the end of every four or five years. The latter acre will be kept up, by these successive additions, to its maximum state of productiveness of 30 bushels of wheat, the former will by degrees become less productive, and will gradually revert to its original condition.

Suppose no diminution in the crops to become sensible before the end of the first ten years—which will rarely happen—but that during the next ten the diminution becomes constantly greater, till at the end of the twentieth year the produce is reduced to 20 bushels a-year, on that acre to which no new dose of lime has been applied. This will be equal to an average produce of 25 bushels an acre during the latter ten years, or 250 bushels in the whole.

But the other acre, which is regularly limed, has yielded every year at the rate of 30 bushels, or 300 bushels in these ten years. The account between the two acres, therefore, for this second period of ten years stands thus

10 crops of 30 bushels amount to 300 bushels;
10 crops of 25 bushels amount to 250 bushels;

Being a difference of .... 50 bushels in favour of the frequently limed field; or *nearly two entire crops every lease of twenty years.*

This calculation is made on the supposition that the full effect of the first dose of lime continues for ten years, which experience says is very seldom the case. The result is, therefore, even more favourable than

it ought to be to the large-and-seldom-dose system. I might consequently have estimated the probable profit of frequent doses still higher, but as I am only anxious to lead the practical man to the adoption of that method which will put most money into his pocket, I leave the above moderate estimate of its economical value to his candid consideration.

SECTION IV.—INFLUENCE OF TENURE ON THE MODE OF LIMING.

But the kind of tenure on which a farm is held materially influences the mode in which the tenant considers himself justified in applying lime to his land.

1°. When the land is held on a lease of 19 or 21 years, and when within 10 years of the end of his lease, the tenant can make arrangements to have his lease renewed at a fair rent; he is then in the best possible circumstances for treating the land well, because it will be most profitable to himself as well to the landlord. He may then lime largely at first, and may at frequent intervals add smaller doses, so as to maintain the land continually in the highest state of productiveness. But

2°. If the tenant holds by a 19 years lease, and has no certainty of continuing, or no desire to continue after the expiry of that term, he may lime largely during the first rotation, but during the last two rotations, his interest is to get as much out of the land as he can before he leaves it, and therefore he adds nothing which he can possibly avoid.

In leases of this kind the tenant only limes once, as is much the case in Roxburgh and some of the adjoining counties—or he limes twice in his lease of 21 years, as is occasionally done in Renfrewshire, West Lothian, and York, Durham, and other English counties in which land is held on lease—or he limes once in six or eight

years, as is frequent in Ayrshire, the Carse of Stirling, and parts of Wales. By this means the full or main virtue of the lime has been exhausted for his benefit before his tenure of the land has expired.

3°. In many leases and agreements the condition is still expressed, that the tenant shall either lime or manure every six or eight years—in others, he is bound both to lime and manure within a stated number of years. In such cases as these, the tenant has no choice, and the tenure by which he holds alone determines the important question, of how much as well as how often, lime is to be applied to his land.

4°. Where there are no leases, therefore, it would appear at first sight as if circumstances would be more favourable to the exercise of that skilful discrimination and choice in regard to the mode of liming, by which the instructed farmer will be enabled to benefit in the highest degree the land he cultivates.

But this is by no means the case. Other cross circumstances here come in which disturb the mind of the tenant as to the economy or propriety of this as well as of many other modes of improvement. His tenure is certain for one year only. The lime he applies will produce its full effect only after several years. Should any circumstance arise, therefore, to deprive him of his farm—should he himself die, or his landlord, or the steward—his family would in most cases lose the money he had invested in lime with a view to after profit, and buried in his land. There is no doubt that this consideration influences the conduct of the yearly tenant, not only in reference to the application of lime, but in reference also to other operations he might profitably undertake. It operates often unconsciously, and becomes, after a generation or two, a kind of general habit or rule of conduct—opposing itself to all unnecessary outlay and to every thing like speculative trials—which

habit among a body of tenantry is often to be overcome only by a large infusion of new blood.

The remedy is simple. Let compensation be given to the tenant for all unexhausted improvements, according to a fair and reasonable scale, and this form of hindrance at least will no longer exist to the employment of the best modes of farming, even though they should involve a larger outlay of money, and for a longer period of time.

I would not recommend the introduction into this country of the tenant right of the sister island—the Scotch lease is I believe fairer to all parties—yet unless the custom of making allowances for liming and other improvements be guaranteed to the retiring tenant, the best management of the land can never be secured.

Though, therefore, both theory and practice concur in shewing that the method of frequent liming is most likely to maintain the highest fertility of the land, yet it is evident that the peculiar circumstances in which the farmer is placed must materially affect the course of conduct which it will be most prudent for him to adopt.

One thing, however, I would repeat, must be borne in mind by those who, in adopting the best system of liming, do not wish both to injure their land and to meet with ultimate disappointment. Organic matter—in the form of farm-yard manure, of bone or rape-dust, of green crops ploughed in, or of peat, and other composts—must be abundantly and systematically added, if at the end of 20 or 40 years the land in which the full supply of lime is kept up is to retain its original fertility. High farming is the most profitable—for the soil is ever grateful for skilful treatment—but he who farms high in the sense of keeping up the supply of lime, must also farm high in the sense of keeping up the supply of organic and other manures in the soil—otherwise present fertility and gain will be followed by

future barrenness and loss. If this is not to be done, it were better to add lime at long intervals, since as the quantity of lime diminishes, the land begins to enjoy a little respite, and has had time in some measure to recover itself—the cropping in both instances being the same—before the new dose is laid upon its surface.*

SECTION V.—OF THE LENGTH OF TIME DURING WHICH LIME ACTS, AND OF COMPENSATION FOR LIMING.

The length of time during which lime acts is a question of considerable practical importance in reference—

1°. To the proper time of applying a renewed application.

2°. To the expense of cultivating the land during a series of years.

3°. To the amount of compensation which ought to be allowed to a way-going tenant for the lime he has added to his land.

The last of these, in cases where disputes arise between landlord and tenant, becomes often a question of very considerable importance.

The length of time during which a given dose of lime may be expected to benefit the land depends upon a variety of circumstances, such as the quality of the lime—the physical character of the soil—the quantity of lime it previously contained—the kind of husbandry or course

* "In the neighbourhood of Taunton, in Somersetshire, and over all the soil of the new red sand-stone, the farmers lime their land every time it comes in course to fallow for turnips, and this produces excellent crops, even without dung."—*Morton on Soils*, third edition, p. 181. The practical reader must not consider this custom of the Somersetshire farmers as at all at variance with what is stated in the text; he must conclude, rather,—if the sentence here quoted is meant to imply that they lime their arable land so repeatedly, and yet add no organic manure—that they will, sooner or later, cease to boast of its fertility.

of cropping that is followed—the quantity of rain that falls—the state of the drainage, and other considerations of a similar kind. These can only be ascertained by actual investigation in each locality. The opinion of practical men in the best cultivated districts, therefore, is perhaps the best *general* guide we at present possess.

a. In Lincolnshire, where the tenants not unfrequently have a clause in their leases entitling them to compensation for improvements, it is usual to allow seven years for marl or lime; so that if the tenant leave his farm only one year after the lime is applied, he is entitled to six-sevenths of the cost of applying it; if two years after, five-sevenths, and so on. In other parts of the same county, ten years are allowed for marl and seven for lime.* This distinction is probably made because the marl acts more slowly, and being laid on in larger doses, acts also for a longer time.

At a late agricultural meeting, held at Loughborough, an allowance of five years for lime was considered sufficient, and was embodied in a code of resolutions in reference to such points, which was adopted and recommended by the practical farmers of that neighbourhood.

b. In Scotland, I am not aware of any district in which a recognised principle of this kind is known or acted upon. The custom of granting leases during the currency of which the tenant is to remunerate himself for *every thing* he does to the land, giving it up at the end of the term, free, to the landlord;—this custom has obtained such universal prevalence, that no idea is entertained, and no provision usually made, for compensation to a way-going tenant when his lease has expired.

A break, however, sometimes occurs in the lease, in the event of which being taken advantage of, compensation is made to the tenant for liming and other im-

* Royal Agricultural Journal, V., p. 347.

provements. The determination of the amount of such compensation, in the absence of specific clauses, becomes a matter of great difficulty. Where the custom prevails of adding lime only once during the currency of the lease, the tenant naturally believes that he will only have extracted the full benefit of the lime he has added when the end of his lease has come. And, forgetting that during the last half of his lease the sensible effect of the lime is constantly diminishing, practical men are inclined to claim and to allow each other a proportion of the cost equal to that which the number of years the lease has to run bears to the whole term of the lease. Thus, if nine of the nineteen years have to run, the tenant is allowed nine-nineteenths of the cost of lime and cartage, and if eight years, eight-nineteenths, and so on. This allowance, as a general rule, is too high.

Where it is customary to lime more frequently, once every six or eight years for example, a fair allowance is more easily made. Indeed the custom of the district must be taken into account wherever an allowance is made or claimed for liming—but I doubt much if, in any old cultivated land, more than ten or twelve years should be allowed for such a beneficial action of lime or marl, as to entitle the tenant to a compensation for applying them.

There was much good sense and experience, I think, in the opinion of an old East Lothian farmer whom I lately consulted on the subject. "For *a large dose* of lime," he said, "I would allow—after three years, one-half; after six years, one-third; after eight years, one-fourth, or less." This was on land long cultivated on the four-course system, and probably frequently limed before.

In awarding compensation, however, regard should also be had to the previous condition of the land to

which the lime or chalk has been applied. If the land has been limed or chalked for the first time, it is the result of universal experience either upon the stiff clays of the south or the heathy hills of the north, that a much greater benefit and for a longer period is produced than by any subsequent liming of an equal extent. The increased value of the land to the tenant therefore—his beneficial interest that is—is greater,—and he is entitled to a pecuniary compensation in some degree proportionate. On the other hand, if the experience of the neighbourhood has already proved that liming of a particular kind or under particular circumstances does little good, it would be unfair, in the event of his removal, to allow compensation for an outlay which may have been made contrary to the sense and experience of the district—the benefits of which also are not distinctly visible. But as no general rule can be laid down which local circumstances will not modify, the safest way in all cases is to provide in the covenants between landlord and tenant for such probable claims and contingencies.

c. In some parts of England, where the land is held on a yearly tenancy, the retiring tenant is allowed to make an agreement with his successor—in some cases himself to select a person who will comply with his own conditions, while he is also acceptable to the landlord. This is very like the tenant-right of the north of Ireland, and has certainly the advantage of keeping the landlord and his tenantry from coming into unpleasant collision.

CHAPTER V.

Effects of lime upon the soil and the crops. Effects of marl, coral sand, shell sand, and limestone gravel. Effects of chalk. Effects produced by burned and slaked lime. Influence of circumstances in modifying its effects. State in which lime should be applied to different soils. Use and advantage of the compost form. Effects of an overdose of lime, and how they are to be counteracted.

Lime is largely applied to the land in the unburned as well as in the burned state. In the former state it exists in marl, in coral, shell, and limestone sands, in crushed limestone, and in chalk. In all these forms it is very extensively and economically employed by the practical farmer.

SECTION I.—EFFECTS OF MARL, OF SHELL, CORAL, AND LIMESTONE SANDS, AND OF CRUSHED LIMESTONE.

The effects which result from the application of these natural forms of unburned lime—carbonate of lime—are of two kinds.

1°. Their *physical* effect in altering the natural texture of the soils to which they are added. This effect will necessarily vary with the nature and proportion of the earthy matter associated with the lime. Thus the clay marls, as in Norfolk, will improve, by stiffening, light and sandy soils—the shell sands and limestone gravels, by opening and rendering more free and easier worked such soils as are stiff, intractable, and more or less impervious—while either will impart solidity and substance to such as are of a peaty nature or over-abound with other forms of vegetable matter.

2°. Their *chemical* effect in actually rendering the soil productive of larger crops. This effect is altogether independent of any alteration in the physical properties of the soil, and is nearly the same in *kind*, whatever be the variety of marl, &c., we apply. It differs in *degree*, chiefly according to the proportion of calcareous matter which each variety contains. This action of the pure carbonate of lime they contain is no doubt modified in some cases by the proportion of phosphate of lime, &c. (p. 10) with which it may be mixed—it is also modified by the animal and saline matters which are present in the recent corals and shell sands.

The effects of marl and calcareous sand being dependent upon circumstances so different, it is not surprising that the opinions of practical men should be divided in regard to the action of this or that marl upon their respective soils. The substance applied to the land is seldom exactly alike in any two localities, and hence unlike results must necessarily follow, and disappointment be occasionally experienced from their use. And yet the importance of rightly understanding the kind and degree of effect which these manuring substances ought to produce in different circumstances may be estimated from the fact, that a larger surface of the cropped land in Europe is improved by the assistance of calcareous marls and sands—than by the aid of both burned lime and of farm-yard manure put together.

It is not easy in any case to estimate with precision what portion of the effect caused by a given marl is due to its chemical and what to its physical action. Even the pure limes, when applied in large doses, produce a change in the texture of the soil, which on stiff lands is beneficial, and on light or sandy fields is often injurious. In all cases, therefore, the action of lime applied in any form may be considered as partly physical and partly chemical—the extent of the chemical action in general

increasing, as I have said, with the proportion of lime which the kind of calcareous matter employed is known to contain.

3°. The *observed* effects of marl and shell sands, in so far as they are chemical, are chiefly the following—

They alter the nature and quality of the grasses when applied to pasture—they cover even the undrained bog with a short rich grass—they extirpate heath, and bent, and useless moss—they exterminate the weeds which infest the unlimed corn fields—they increase the quantity and enable the land to grow a better quality of corn—they manifest a continued action for many years after they have been applied—like the purer limes they act more energetically if aided by the occasional addition of other manure—and like them they finally exhaust* a soil from which successive crops are reaped, without the requisite return of decaying animal or vegetable matter.

SECTION II.—EFFECTS OF CHALK.

Of the use of chalk as an improver, I have already treated in a previous chapter (p. 26). It is applied more or less extensively over all that part of England where the soils rest upon or are within reach of the beds of chalk.

Chalk consists not merely of finely divided particles of carbonate of lime, but like the fresh water marls (p. 17) not unfrequently in great part of the skeletons, shells, and other spoils of minute animals—of marine origin in this case, and generally to be detected only by the use of the microscope. Hence chalk usually contains traces of animal matter—particles of silica, the substance of flint, retaining the forms they possessed

* Of shell marl the same quantity exhausts sooner than clay marl (Kames). This is owing probably to the larger proportion of lime contained in the former.

when attached to the living sponge or infusorial animal of which they formed a part—traces of phosphate of lime, the material of bones, also derived from the bodies of animals—and indefinite quantities of the various saline substances which are dissolved in sea water.

But the proportion of all these substances varies in different beds of chalk and in different localities. Its particles also differ in their degree of fineness, and the proportion of mud or clay with which they are mixed is very fluctuating. All these circumstances must modify very much the agricultural effect of chalk, especially in so far as it is of a chemical nature.

Hence the quantity applied to the land varies both with the nature of the land itself and with the quality of the chalk, with the more or less perfect crumbling also which it undergoes by the action of the winter's frost and with the purpose it is intended to serve.

It produces physical as well as chemical improvements.

1°. It opens and imparts freeness to stiff clays. The first and leading principle on the London clays, and indeed upon all the stiff clays within its reach, is the application of chalk. This in every instance, it is said, on the first application produces an astonishing change upon the soil, enabling it to produce valuable crops for many years afterwards without the assistance of any additional manure. It is afterwards applied along with other manures to diminish the tenacity of the soil and thus to render it more porous.

2°. It adds firmness to such as are of a sandy nature, so that blowing sands are consolidated, while naturally sterile sands have in some localities been brought into a state of comparative fertility, by large applications of it.

3°. It gives tenacity and closeness to gravelly soils. Mr. Gawler states that a Hampshire gravel thus stif-

fened, instead of 12 to 16 bushels of wheat, yielded afterwards 24 to 30 bushels.*

If a physical improvement of this kind is required, it is laid on at the rate of from 400 to 1000 bushels an acre. But some chalks contain more clay than others, and are employed therefore in smaller proportions.

It acts chemically also in many ways. Thus—

1°. It improves coarse, sour, marshy pasture, and speedily brings up a sweet herbage. For this purpose it is applied at the rate of 150 to 250 bushels an acre. It is also said to root out sorrel from fields infested by this plant.

2°. On the *deep lands* as they are called, in the wolds of York and Lincoln—where the soil which lies above the chalk is deepest—corn does not yield so well nor ripen so early as when a thinner covering rests upon the chalk. It is also naturally unfit for barley and turnips—the latter plant being especially infested with the disease called fingers and toes (Strickland). A heavy chalking of 60 to 80 cubic yards per acre removes all the above defects of these deep soils and for a long period of time. The corn ripens sooner, is larger in quantity and better in quality, and the turnips grow perfectly free from disease.

SECTION III.—EFFECTS OF BURNED AND SLAKED LIME UPON THE LAND.

Pure or quick lime, like the marls and shell sands, produces both a mechanical and a chemical effect upon the soil. The former is constant with all varieties of tolerably pure lime and is easily understood. It opens and renders freer such soils as are stiff and clayey, while

* British Husbandry, I., p. 280.

it actually consolidates such as are light and sandy. In some districts it is said to stiffen one-half as much as clay. In large doses it causes moorish and peaty soils in arable culture to heave, loosen, and become hollow under the foot, but it is upon such soils alone that its mechanical effects are usually unfavourable.

From its chemical action the benefits which follow the use of lime are chiefly derived. These benefits are principally the following:—

1°. It increases the fertility of all soils in which lime does not already abound, and especially adds to the productiveness of such as are tenacious, moist, or contain much inert vegetable matter.

2°. It enables the same soils to produce crops of a superior *quality* also. Land which, unlimed, will produce only a scanty crop (3 to 4 fold) of rye, by the addition of lime alone, will yield a 6 or 7 fold return of *wheat*. From some clays, also, apparently unfit to grow corn, it brings up luxuriant crops.

3°. It increases the effect of a given application of manure; calls into action that which, having been previously added, appears to lie dormant; and, though manure must be plentifully laid upon the land, after it has been well limed, yet the same degree of productiveness can still be maintained at a less cost of manure than where no lime has been applied.

4°. As a necessary result of these important changes, the money value and annual return of the land is increased, so that tracts of country which had let with difficulty for 5s. an acre have in many localities been rendered worth 30s. to 40s. by the application of lime alone (Sir J. Sinclair). On the northern slopes of hill land above the Laigh of Moray the value of large tracts of land has been tripled by the use of lime.

SECTION IV.—EFFECTS OF LIME ON THE PRODUCTIONS OF THE SOIL.

1°. *It alters the natural produce of the land,* by killing some kinds of plants and favouring the growth of others, the seeds of which had before lain dormant. Thus it destroys the plants which are natural to silicious soils and to moist and marshy places. From the corn-field it extirpates the corn-marigold *(Chrysanthemum segetum)*,* while, if added in excess, it encourages the red poppy, the yellow cow-wheat *(Melampyrum pratense)*, and the yellow rattle *(Rhinanthus crista galli)*, and when it has sunk, favours the growth of the troublesome and deep-rooted coltsfoot.

Similar effects are produced upon the natural grasses. It kills heath, moss, and sour and benty† *(agrostis)* grasses, and brings up a sweet and tender herbage, mixed with white and red clovers, more greedily eaten by and more nourishing to the cattle. Indeed all fodder, whether natural or artificial, is said to be sounder and more nourishing when grown upon land to which lime has been abundantly applied.‡

On benty grass the richest animal manure often produces little improvement until a dressing of lime has been applied. This is especially the case when lime is laid upon land for the first time. The physical improvement, even, is so marked that in some instances it is

* Bönninghausen.

† In Liddisdale, on the Scottish border, is a large tract of land in what is there called *flying bent*, not worth more than 3s. per acre. If surface-drained and limed at a cost of £2. to £3. an acre, this becomes worth 12s. an acre for sheep pasture. An experienced border farmer assures me that such land would *never forget* 40 to 60 bushels of lime per acre.

‡ The liming of the pastures at Closeburn imparts a deep rich yellow to the fat of the animals fed upon it, which otherwise would have been white (Sir Chas. Monteath).

said the mere saving of labour in ploughing up would be sufficient to compensate a farmer for liming, were no other benefit derived from the application—from the more perfect and economical manner in which he would be able to work his land.

It is partly in consequence of the change which it thus produces in the nature of the herbage, that the application of quick lime to old grass lands, sometimes before breaking up, is found to be so useful a practice. The coarse grasses being destroyed, *tough* grass land is opened and softened, and, as I have said, is afterwards more easily worked, while, when turned over by the plough, the sod sooner decays and enriches the soil. It is another advantage of this practice, however, that the lime has time* to diffuse itself through the soil, and to induce some of those chemical changes by which the succeeding crops of corn are so greatly benefitted.

2°. *It improves the quality of almost every cultivated crop.* Thus, upon limed land—

a. The grain of the corn crops has a thinner skin, is heavier, and yields more flour. This flour is said also to be richer in gluten, a point however which is very doubtful and requires experimental confirmation. On the other hand, these crops, after lime, run less to straw, and are more seldom laid. In wet seasons (in Ayrshire) wheat preserves its healthy appearance where lime has been applied, while on unlimed land, of equal quality, it is yellow and sickly. A more marked improvement is said also to be produced both in the quantity and in the quality of the spring-sown than of the winter-sown crops (Puvis). It hardens the straw and makes the wheat a finer sample.

* A comparatively long period is sometimes permitted to elapse before the grass land is broken up after liming. Thus at Netherby, "lime or compost is always applied to the third year's pasture, which is renovated by it, and in two or three years breaks up admirably for oats."

b. Potatoes grown upon all soils are more agreeable to the taste and more mealy after lime has been applied, and this is especially the case on heavy and wet lands which lie still undrained.

c. Turnips are often improved both in quantity and in quality when it is laid on in preparing the ground for the seed. It is most efficient, and causes the greatest saving of farm-yard manure where it is applied in the compost form, and where the land is already rich in organic matter of various kinds.

d. Peas are grown more pleasant to the taste, and are said to be more easily *boiled soft*. Both beans and peas also yield more grain (see Brit. Husb., I., p. 217).

e. Rape, after a *half*-liming and manuring, gives extraordinary crops, and the same is the case with the *colza,* the seed of which is largely raised in France and Holland for the oil which it yields.

f. On *flax* alone it is injurious, diminishing the strength of the fibre. Hence, in Belgium, flax is not grown on limed land till seven years after the lime has been applied. Something, however, depends upon the soil.

3°. *It hastens the maturity of the crop.*—It is true of nearly all our cultivated crops, but especially of those of corn, that their full growth is attained more speedily when the land is limed, and that they are ready for the harvest from 10 to 14 days earlier. This is the case even with buck-wheat, which becomes sooner ripe, though it yields no larger a return when lime is applied to the land on which it is grown.*

* It is said that in East Northumberland the liming of the land does not hasten the ripening of the crop. It makes the land more productive and the crop larger, though not ready to cut at so early a period. This is explained on the spot, by saying that the growth of straw and ear being greater than before, the ripening is retarded by this cause. If this statement be correct, it is more probably connected with the extensive want of drainage. In Caithness bog-marl is said to make the oats later, quicklime earlier.

4°. The liming of the land is the harbinger of health as well as of abundance. It salubrifies no less than it enriches the well cultivated district. This is one of the incidental results which also follow the skilful introduction of the drain over large tracts of country. Where the use of lime and of the drain go together it is difficult to say how much of the increased healthiness of the district is due to the one improvement, and how much to the other. The lime arrests the noxious effluvia which tend to rise more or less from every soil at certain seasons of the year, and decomposes them or causes their elements to assume new forms of chemical combination, in which they no longer exert the same injurious influence upon animal life. How beautiful a consequence of skilful agriculture that the health of the community should be promoted by the same methods which most largely increase the produce of the land! Can we doubt that the All-benevolent places this consequence so plainly before us as a stimulus to further and more general improvement—to the application of other knowledge still to the amelioration of the soil?

SECTION V.—CIRCUMSTANCES BY WHICH THE EFFECTS OF LIME ARE MODIFIED.

These effects of lime are modified by various circumstances. We have already seen that the quantity which must be applied to produce a given effect, and the form in which it will prove most advantageous are, in a great measure, dependant upon the dryness of the soil, upon the quantity of vegetable matter it contains, and on its stiff or open texture. There are several other circumstances, however, to which it is proper still to advert. Thus—

1°. Its effects are greatest when well mixed with the

soil, and *kept near the surface within easy reach of the atmosphere.* The reason of this will hereafter appear.

2°. Among arable soils of the same kind and quality the effects are greatest upon such as are newly ploughed out, or upon certain subsoils when just brought to day. In the case of subsoils this is owing partly to their containing naturally very little lime, and partly to the presence of noxious ingredients, which lime has the power of altering. In the case of surface soils newly ploughed out, the greater effect, in addition to these two causes, is due also to the large amount of vegetable and other organic matter which has gradually accumulated within them. It is the presence of this organic matter which has led to the establishment of the excellent practical rule—"*that lime ought always to precede putrescent manures when old leys are broken up for cultivation.*"

3°. Its effects are greater on certain geological formations than on others. Thus it produces much effect on drifted (diluvial) sands and clays—on the soils of the London, the plastic, and the wealden clays—on those of the new and old-red sandstones, of the granites, and of many slate-rocks—and, generally, on the soils formed from all rocks which contain little lime, or from which the lime may have been washed out during their gradual degradation.

On the other hand, it is often applied in vain to the soils of the oolites, and other calcareous formations, because of the abundance of lime already present in them. The advantage derived from chalking thin clay soils resting immediately upon the chalk-rock, is explained by the almost entire absence of lime from these soils. The clay covering of the chalk wolds has probably been formed, not from the ruins of the chalk rock itself, but from the deposit of muddy waters, which rested upon it for some time before those localities became dry land.

4°. Lime produces a greater *proportional improve-*

ment upon poor soils than on such as are richer (Dr. Anderson). This also is easily understood. It is of poor soils in their *natural state* that Dr. Anderson speaks.* In this state they contain a greater or less quantity of organic matter, but are nearly destitute of lime, and hence are in the most favourable condition for being benefitted by a copious liming. Experience has proved that by this one operation such poor land may be raised in money value eight times, or from 5*s*. to 40*s*. per acre; but no practical man would expect that good arable land already worth £2. per acre could, by liming or any other single operation, become worth £16. per acre of annual rent. The greater proportional improvement produced upon poor lands by lime is only an illustration, therefore, of the general truth—that on poor soils the efforts of the skilful improver are always crowned with the earliest and most apparent success.

5°. In certain cases the addition of lime, even to land in good cultivation, and when put on according to the ordinary and approved practice of the district, produces no effect whatever. This is sometimes observed where the custom prevails, as in some parts of Ayrshire and elsewhere, of applying lime along with every wheat crop, and on such farms especially where the land is of a lighter quality. Where from 40 to 60 bushels of lime are added at the end of each rotation of four or five years, the land may soon become so saturated with lime that a fresh addition will produce no sensible effect. Thus Mr. Campbell, of Craigie, informs me of a trial made by an intelligent farmer in his neighbourhood where alternate ridges only were limed without any sensible

* "I never met," he says, "with a poor soil in its *natural state*, which was not benefitted in a very great degree by calcareous matter when administered in proper quantities. But I have met with several rich soils, which were fully impregnated with dung, on which lime applied in any quantity produced not the smallest sensible effect."

difference being observed. No result could show more clearly than this—that for one rotation at least the expense of lime might have been saved, while at the same time the land would have run less risk of exhaustion. Another fact mentioned by Mr. Campbell proves the soundness of this conclusion. The lime never fails to produce obvious benefit where the land is allowed to be four or five years in grass—where it is applied, that is, only once in eight or nine years. The fair inference is, therefore, that in this district as well as in others where similar effects are observed—too much lime is habitually added to the land, whereby not only is a needless expense incurred, but a speedier exhaustion of the soil is insured. Good husbandry, therefore, indicates either the application of a smaller dose at the recurrence of the wheat crop—the occasional omission of lime altogether for an entire rotation—or a more liberal habit of manuring at the same time.

6°. On poor arable lands, which are *not* naturally so, but which are worn out or exhausted by repeated liming and cropping, lime produces no good whatever* (Anderson, Brown, Morton). Such soils, if they do not already abound in lime, are, at least, equally destitute of numerous other kinds of food, organic and inorganic, by which healthy plants are nourished,—and they are only to be restored to a fertile condition by a judicious admixture of all. This truth is confirmed by the practical observation, that on soils so exhausted farm-yard manure along with the lime does not produce the same good results as in other cases. *All* that the soil requires is not supplied in sufficient abundance by these two substances laid on alone.

* "It is scarcely practicable to restore fertility to land, even of the best natural quality, which has been thus abused; and thin moorish soils, after being exhausted by lime, are not to be restored" (Brown). Chemical knowledge now teaches us how to effect what Mr. Brown, with the knowledge of his time, considered impossible.

7°. On lands of this kind, and on all in which vegetable matter is wanting, lime may even do harm to the immediate crop. It is apt to *singe* or *burn* the corn sown upon them (Brown)—an effect which is probably chemical, but which may in part be owing to its rendering more open and friable soils which through long arable culture are too open already (Morton).

8°. A consideration of the circumstances above adverted to explains why, in some districts, and even in some whole provinces, the use of lime in any form is condemned and even entirely given up. The soil has been impoverished through its unskilful application—or, by large admixtures of lime or marl for a series of years, the soil has been so changed as to yield no adequate return for new additions. Thus for a generation or two the practices of liming and marling are abandoned, to be slowly and reluctantly resumed again, when natural causes have removed the lime from the soil, and produced an accumulation of those other substances which, when associated with it, contribute to the productiveness of the land.

SECTION VI.—STATE IN WHICH LIME SHOULD BE APPLIED TO DIFFERENT SOILS.

The form or state in which lime ought to be applied to the land depend upon the nature and condition of the soil, the kind of cropping to which it is subjected, and the special purpose which the lime is intended to effect. The soil may be heavy or light, covered by natural heath, in arable culture, or laid down to grass, and each of these conditions indicates a different mode of procedure in the application of lime. So the lime itself may be intended either to act more immediately or to be more permanent in its action—or it may be

applied for the purpose of destroying unwholesome herbage, of quickening inert vegetable matter, of generally sweetening the soil, or simply of adding to the land a substance which is indispensable to its fertility. The skilful agriculturist will modify the form and mode of application according as it is intended to serve one or another of these purposes.

From the considerations already presented (p. 43) in regard to the changes which quick-lime undergoes in the air, it appears to be expedient

1°. To slake lime quickly and to apply it immediately upon clay, boggy, marshy, or peaty lands—upon such also as contain much inert or generally which abound in other forms of vegetable matter.

2°. To bents and heaths which it is desirable to extirpate, it should be applied in the same caustic state, or to unwholesome subsoils which contain much iron, as soon as they are turned up by the plough. In both these cases the unslaked lime-dust from the kilns might be laid on with advantage.

3°. Where it is to be spread over grass lands without destroying the herbage, it is in most cases safer to allow the lime to slake spontaneously, and in the open air than in a covered pit. It is thus obtained in the state of an exceedingly fine powder, which can be easily spread, and while it is sufficiently mild to leave the tender grasses unharmed, it contains still a sufficient quantity of caustic lime to produce those chemical changes in the soil on which the efficacy of quick-lime depends.

4°. Where lime is applied to the naked fallow, is ploughed in, and is then well harrowed or otherwise mixed with the soil, it is generally of little consequence in which of the above states it is laid on. The chief condition is, that it be in a state of fine powder, and that it be well spread and intimately mixed with the

soil. Before these operations are concluded the lime will be very nearly in the same state of combination in which it exists in spontaneously slaked lime—whatever may have been the degree of causticity in which it had been applied.

5°. To light and thin soils, to sands and gravels which are poor in vegetable matter, to drained peats, or to heathy moor-lands, caustic lime, if applied at all, ought to be so only the first time lime is applied to them—or, if afterwards, very sparingly and with great caution.

To heaths and moors when first reclaimed, it may be proper to add a moderate dressing of lime in the caustic state, but after they have been some time in arable culture, long-slaked mild lime or lime composts are much safer forms of cultivation. Where the land is in permanent pasture, not intended to be broken up, it is of less consequence in what form the lime is laid upon the land.

SECTION VII.—USE AND ADVANTAGE OF THE COMPOST FORM.

As there are many cases in which lime ought to be applied unmixed and in the caustic state, so there are others in which it is best and most beneficially laid upon the land in a mild state and in the form of compost or *mixens*.

1°. When lime is required only in small quantities, it can be more evenly spread when previously well mixed with from three to eight times its bulk of soil.

2°. On light, sandy, and gravelly soils, when of a dry character, unmixed lime tends to bring up much cow-wheat *(melampyrum)* and red poppy. If they are moist soils, or if rainy weather ensue, the lime is apt to run to mortar, and thus to form either an impervious sub-

soil, or lumps of a hard conglomerate, which are brought up by the plough, but do not readily yield their lime to the soil. These bad consequences are all avoided by adding the lime in the form of compost.

3°. To grass lands—unless the soil be stiff clay or wet and undrained, or where coarse grass and weeds or moss are to be extirpated—it is better and safer, and has generally been found more beneficial to apply it in the compost form. The action of the lime on the tender herbage is moderated, and its exhausting effect upon soils which contain little vegetable matter is lessened, when laid on in this form.

4°. In the compost form the same quantity of lime acts more immediately. While lying in a state of mixture, those chemical changes which lime either induces or promotes have already to a certain extent taken place, and thus the sensible effect of the lime becomes apparent in a shorter time after it has been laid upon the land. This is still more distinctly the case when, besides earthy matter, decayed vegetable substances—such as ditch scourings, and other refuse—are mixed with the lime. The experience of every practical man has long proved how very much more enriching such composts are, and how much more obvious in their effects upon the soil, than the simple application of lime alone.

5°. It is stated as the result of extended trials in Flanders and in some parts of France, that a much smaller quantity of lime laid on in this form will produce an equal effect.

6°. The older the compost the more fertilizing is its action. This fact is of the same kind with that generally admitted in respect to the action of marls and unmixed lime—that it is more sensible in the second year or in the second rotation than in the first.

In conclusion, it may be stated that this form of application is especially adapted to the lightest and driest soils, and to such as are poorest in vegetable matter.

In this form, lime has imparted an unexpected fertility even to the white and barren sands of the *Landes* in Southern France (Puvis), and upon the dry hills of Derbyshire it has produced an almost equal benefit. Skilful practical men say that to moorish soils lime should never be added a second time unless in the form of compost, and that then it is prudent to lay them down to grass.

SECTION VIII.—EFFECTS OF AN OVERDOSE OF LIME, AND HOW THEY ARE TO BE COUNTERACTED.

There are several effects which are familiar to the practical man as more or less observable where lime in any form is laid too lavishly or too repeatedly upon the land. Thus—

1°. By an overdose of quick lime some soils are hardened to such a degree as to become impervious to water or to the roots of plants. Several parts of the Carse of Gowrie were formerly rendered so hard by the addition of lime as to be unfit for vegetation* (Kames). This effect I have never seen. It will be observed, I should think, only in soils which are naturally wet and undrained, or where much rain has fallen and lingered on the land after the lime has been applied.

2°. Some soils are rendered so loose by lime as to be capable of holding no water (Kames). Upon stiff clays a very large application indeed will be required to produce this effect. It happens chiefly on moorish or peaty soils under arable culture.

In many parts of Scotland the supposed effects of over-liming on thin moorish soils or on reclaimed peat are frequently seen. The land is hollow to the tread—the foot sometimes sinks into it—it is open, light, and porous. Turnips and barley grow well upon it, but oats and clover refuse to yield profitable returns. It is in fact too light and open for these latter crops, which

* Gentleman Farmer. Edition 1802.

require a certain degree of tenacity in the soil in which their roots are to fix themselves.

This condition of the soil is usually ascribed to too large additions of lime being made, and the expression *over-limed*, applied to land in this state, seems to imply that too large a proportion of lime is still actually contained in it.

With the view of ascertaining how far this is really the case, I procured from Ballindalloch, in Banffshire, several specimens of soil in this light, porous, over-limed condition, in which they were incapable of growing oats and clover; and I submitted them to analysis. The following were the results of the examination of three of the specimens:—

	1.	2.	3.
Organic matter	10·29	9·54	5·65
Salts soluble in water	0·45	0·15	0·50
Oxides of iron	2·49	3·68	0·50
Alumina	1·71	2·54	1·11
Carbonate of lime	1·40	0 69	1·10
Oxide of manganese	trace	0·72	trace
Carbonate of magnesia	trace	trace	trace
Insoluble matter, chiefly sand	81·77	82·79	91·20
	98·11	100·11	100·06

These results show that so far from the proportion of lime in the soil being excessive it is in reality deficient. Among the chemical means by which these soils are to be brought to their highest state of productiveness the actual addition of lime therefore is one.

The evil called over-liming is consequently a mechanical and not a chemical one. The extreme openness of the soil has been brought on by prolonged ploughing and too frequent cropping with corn. An opposite procedure, therefore, must be adopted, and mechanical means employed by which a gradual solidification may be effected. For this purpose several methods are to be recommended.

1°. Eating off the turnips and clover with sheep. This method is in fact found to solidify it at Ballendalloch, so as to make it capable of bearing oats.

2°. Laying down to pasture for a few years, by which the same kind of solidification from the treading of the sheep or cattle will be brought about. It is the treading of the horses as they turn with the plough which, by solidifying them, in so many cases makes the head-ridges yield the heaviest crops.

3°. Ploughing shallow and as seldom as possible. The cultivator may in many cases be substituted for the plough, and thus the loosening of the land in a great degree prevented. The subsoil plough ought to be very cautiously employed on such land, unless it be to break some hard pan beneath. I have known the clover appear very much less luxuriant on a loamy soil where the subsoil plough had been used in preparing for the turnip crop.

4°. Paring the land with the breast-plough, as is practised in Berkshire, Gloucester, and other districts, and either burning or rotting the surface, may also be tried with the prospect of advantage. No deep ploughing being thus indulged in, a firm seed-bed is left for the grain, and if well manured any usual crop may be sown.

5°. I ought to mention, as one of the most injurious accompaniments of over-liming, the exhaustion which the application of lime in repeated doses for a succession of years has hitherto almost unfailingly produced. The frequent ploughing and liming have taken place in order to force from the land frequent crops of corn. While the land was becoming lighter, therefore, it was also becoming poorer; and the full results of over-liming arise out of the operation of these two causes conjoined. While, therefore, the steps above recommended are taken with the view of restoring the mechanical firmness, others no less necessary must be taken to bring back the chemical richness of the soil, before the highest fertility of which it is capable can be successfully secured.

CHAPTER VI.

Theory of the action of lime. General action of lime as a chemical constituent of the soil. Of lime as the food of plants. Relation of the period of growth of a crop to the effect and proportion of lime in the soil. The chemical action of lime is exerted chiefly on the organic matter of the soil. Forms in which organic matter usually exists in the soil. Circumstances under which its decomposition may take place. General action of alcaline substances (potash, soda, &c.) upon organic matter. Special effects of caustic lime upon the several varieties of organic matter in the soil. Summary of the chemical changes which lime and organic matter mutually undergo in the soil. Comparative utility of burned and unburned lime.

The theory of the action of lime upon the land has occupied much attention among practical men in various countries. It may still be difficult to clear up every fact regarding it in a satisfactory manner. Yet in the following sections I hope to present such an explanation of the mode in which it acts, and of the chemical principles by which its action is regulated, as shall be both intelligible to the ordinary reader and generally satisfactory to all.

SECTION I.—GENERAL ACTION OF LIME AS A CHEMICAL CONSTITUENT OF THE SOIL.

Lime, as I have already shown, acts in two ways upon the soil. It produces a *mechanical* alteration which is simple and easily understood, and is the cause of a series of *chemical* changes, which are really obscure, and are as yet susceptible of only partial explanation.

In the finely-divided state of quick-lime, of slaked lime, or of soft and crumbling chalk, it stiffens very

loose soils, and opens the stiffer clays—while in the form of limestone gravel or of shell sand, it may be employed either for opening a clay soil or for giving body and firmness to boggy land. These effects, and their explanation, are so obvious that it is unnecessary to dwell upon them more than has already been done.

The purposes served by lime as a chemical constituent of the soil are at least of four distinct kinds.

1°. In every state of chemical combination it supplies one or more kinds of inorganic food which appear to be necessary to the healthy growth of all our cultivated plants.

2°. In the state of quick-lime or of carbonate it performs three additional functions.

a. It neutralizes acid substances which are naturally formed in the soil, and decomposes other noxious compounds which are not unfrequently within reach of the roots of plants, producing in their stead substances which are not only harmless but often directly useful to vegetation.

b. It changes the inert vegetable matter in the soil, liberates the inorganic substances it contains, and thus gradually renders it useful to vegetation.

c. It aids and promotes the decomposition of the mineral or rocky fragments of which so much of all our soils consists, and thus enables the mineral substances they contain to become useful to the growth of plants.

These several modes of action it will be necessary to illustrate in some detail.

SECTION II.—OF LIME AS THE FOOD OF PLANTS.

On examining the chemical nature of the ash of plants it is found that lime in all cases forms a considerable proportion of its whole weight. Hence the reason why lime is regarded as a necessary food of plants, and hence

also one cause of its beneficial influence in general agricultural practice.

The quantity of pure lime contained in the crops produced upon one acre during a four years' rotation amounts, on an average, to about 200 lbs., equal to 360 lbs. (say 3½ cwt.) of carbonate of lime, in the state of marl, shell-sand, or lime-stone gravel. It is obvious, therefore, that one of the most intelligible purposes served by lime, as a chemical constituent of the soil, is to supply this comparatively large quantity of lime, which in some form or other must enter into the roots of plants.

But the different crops which we grow contain lime in unlike proportions. Thus the average produce of an acre of land under the following crops contains of lime—

	Per Acre.	Grain.	Straw or roots.	Total.
Wheat	(25 bush.)	1	12	13 lbs.
Barley	(40 bush.)	1½	15½	17 lbs.
Oats	(50 bush.)	3	19	22 lbs.
Rye	(26 bush.)	1½	15½	17 lbs.
Beans	(25 bush.)	2½	34	36½ lbs.
Turnips	(20 tons)	46	72	118 lbs.
Potatoes	(8 tons)	8	31	39 lbs.
Red clover ...	(2 tons)	—	77	77 lbs.
Rye grass ...	(2 tons)	—	30	30 lbs.

These quantities are not constant, and generally all our crops contain more lime when grown upon land to which lime has been copiously applied. But the very different quantities contained in the several crops, as above exhibited, shew that one reason *why lime favours the growth of some crops more than others* is, that some actually take up a larger quantity of lime as food. These crops, therefore, require the presence of lime in greater proportion in the soil, in order that they may be able to obtain it so readily that no delay may occur in the performance of those functions or in the growth of those parts to which lime is indispensable.

SECTION III.—RELATION OF THE PERIOD OF GROWTH OF A PLANT TO THE EFFECT AND PROPORTION OF LIME IN THE SOIL.

In connection with the quantities of lime actually found in plants, another important circumstance must be taken into consideration.

Whatever kind or amount of food a plant may require to bring it to maturity, it must collect the whole during the time usually allotted to its growth. Thus the longer a crop is in the ground—the slower it grows, and the longer it usually takes to come to maturity—the more time it has to collect its food from the soil by means of its roots. Barley germinates and ripens its seed within three months—in Sicily sometimes within three weeks—while wheat is from six to ten months in the ground. The roots of barley, therefore, must do much more work in the same time than those of wheat. They must among other things take up the 17 lbs. of lime in the above table in three months, while wheat takes up on an average only 13 lbs. in six months. Now to effect this in the same soil it must send out more roots in quest of this kind of food than the wheat plant will require to do, and thus it must waste more of its vegetative strength under ground. But if we make the supply of lime in the soil more abundant, we diminish the labour of the barley plant and greatly facilitate its growth.

Thus we arrive at the conclusion that the proportion of lime contained in the soil ought to be adapted not only to the proportion which the perfect plant is found to contain and require, but to the period also which is allotted to its natural growth. For crops which run their course quickly, a larger proportion of lime as well as of all other kinds of food will be required—or will be beneficial—than for crops that are longer in coming

to perfection. Has this fact any thing to do with the earlier harvests upon well-limed land—or with its peculiar fitness for the growth of barley?

SECTION IV.—THE CHEMICAL ACTION OF LIME IS EXERTED CHIEFLY UPON THE ORGANIC MATTER OF THE SOIL.

There are four circumstances of great practical importance which cannot be too carefully considered in reference to the theory of the operation of lime. These are—

1°. That lime, unless in the form of compost, has comparatively little or no effect upon soils in which organic matter is deficient.

2°. That its apparent effect, at least upon the corn crop, is inconsiderable during the first year after its application, compared with that which it produces in the second and third years.

3°. That its effect is most sensible when it is kept near the surface of the soil, and gradually becomes less as it sinks towards the subsoil. And

4°. That under the influence of lime the organic matter of the soil disappears more rapidly than it otherwise would do, and that after it has thus disappeared fresh additions of lime are much less beneficial than before.

It is obvious from these facts, that *in general* the main beneficial purpose served by lime is to be sought for in the nature of its chemical action upon the organic matter of the soil—an action which takes place slowly, which is hastened by the access of air, and which causes the organic matter itself ultimately to disappear.

SECTION V.—OF THE FORMS IN WHICH ORGANIC MATTER USUALLY EXISTS IN THE SOIL.

The organic matter which lime thus causes to disappear is presented to it in one or other of five different forms :—

1°. In that of recent, often green, moist, and undecomposed roots, leaves, and stems of plants.

2°. In that of dry, and still undecomposed vegetable matter, such as straw.

3°. In a more or less decayed or decaying state, generally black or brown in colour—and often in some degree soluble in water. In such a state we see it in peat.

4°. In what is called the *inert* state, when spontaneous decay ceases to be sensibly observed. And

5°. In the state of chemical combination with the earthy substances—forming humates, ulmates, &c. (p. 66), with the alumina for example, and with the lime or magnesia which exist in the soil.

Upon these several varieties of organic matter lime acts with different degrees of rapidity.

SECTION VI.—CIRCUMSTANCES UNDER WHICH THE DECOMPOSITION OF THE ORGANIC MATTER MAY TAKE PLACE.

The final result of the decomposition of these several forms of organic matter, when they contain no nitrogen, is their conversion into carbonic acid (p. 2) and water only. They pass, however, through several intermediate stages before they reach this point—the number and rapidity of which, and the kind of changes they undergo at each stage, depend upon the circumstances under which the decomposition is effected. Thus the substance may decompose—

1°. *Alone*, in which case the changes that occur proceed slowly, and arise solely from a new arrangement of its own particles. This kind of decomposition rarely occurs to any extent in the soil, and then only in such as are very compact and impervious to air and water.

2°. *In the presence of water only.*—This also seldom takes place in the soil. Trees long buried in moist clays impervious to air exhibit the kind of slow alteration which results from the presence of water alone. In the bottoms of lakes, ditches, and boggy places also, from which inflammable gases arise, water is the *principal* cause of the more rapid decomposition.

3°. *In the presence of air only.*—In nature organic matter is never placed in this condition, the air of our atmosphere being always largely mixed with moisture. In dry air decomposition is exceedingly slow, and the changes which dry organic substances undergo in it are often scarcely perceptible.

4°. *In the presence of both water and air.*—This is the almost universal condition of the organic matter in our fields and farm-yards. The joint action of air and water, and the tendency of the elements of the organic matter to enter into new combinations, cause new chemical changes to succeed each other with much rapidity. It will, of course, be understood that moderate warmth is necessary to the production of these effects.*

* A familiar illustration of the conjoined efficacy of air and water in producing oxidation (rusting) is exhibited in their action upon iron. If a piece of polished iron be kept in perfectly dry air it will not rust. Or if it be completely covered over with pure water in a well stoppered bottle, from which air is excluded, it will remain bright and untarnished. But if a polished rod of iron be put into an open vessel half full of water, so that one part of its length only is under water—then the rod will begin very soon to rust at the surface of the water, and a brown ochrey ring of oxide will form around it, exactly where the air and water meet. From this point the rust will gradually spread upwards and downwards. So it is with the organic matter of the soil. Wherever

5°. *In the presence of lime* or of some other alcaline substance (potash, soda, or magnesia).—Organic matter is often found in the soil in such a state that the conjoined action of both air and water are unable, without other aid, to hasten on its decomposition. A new chemical agency must then be introduced, by which the elements of the organic matter may again be set in motion. Wood ashes, kelp, carbonate of soda, &c., act in this way, but lime is the agent which for this purpose is most largely employed in practical agriculture.

SECTION VII.—GENERAL ACTION OF ALCALINE SUBSTANCES (POTASH, SODA, ETC.) UPON ORGANIC MATTER.

It is this action of alcaline matters upon the organic substances of the soil in the presence of air and water that we are principally to investigate.

When organic matter undergoes decay in the presence of air and water only, it first rots, as it is called, and blackens, giving off water or its elements chiefly, and forming *humus*—a mixture of humic, ulmic, and some other acids (p. 66) with decaying vegetable fibre. It then commences, at the expense of the oxygen of the air and of water, to form other more soluble acids (malic, acetic, lactic, crenic, mudesic,&c.), among which is a portion of carbonic acid—while by the aid of the hydrogen of the water which it decomposes, it produces also one or more of the many inflammable compounds of carbon and hydrogen, which often rise up, as marsh-gas does from stagnant pools in summer, and escape into the air.

Thus there is a tendency towards the accumulation of

the air and water meet, their decomposing action upon it, in ordinary temperatures, soon becomes perceptible.

acid substances of vegetable origin in the soil, and this is more especially the case when the soil is moist, and where much vegetable matter abounds. The effect of this super-abundance of acid matter is, on the one hand to arrest the further natural decay of the organic matter, and on the other to render the soil unfavourable to the healthy growth of young or tender plants.

The general effect of the presence of alcaline substances in the soil is to counteract these two evils. They combine with and thus remove the sourness of the acid bodies as they are formed. In consequence of this the soil becomes *sweeter* or more propitious to vegetation, while the natural tendeney of the vegetable matter to decay is no longer arrested.

It is thus clear that an immediate good effect upon the land must follow either from the artificial application or from the natural presence of alcaline matter in the soil—while at the same time it will cause the vegetable matter to disappear more rapidly than would otherwise be the case. But the effect of such substances does not end here. They actually dispose or provoke —*pre-dispose* chemists call it—the vegetable matter to produce acid substances, in order that they may combine with them, and thus cause the organic matters to disappear more rapidly than they otherwise would do— in other words, they hasten forward the exhaustion of the vegetable matter of the soil.

Such is the general action of *all* alcaline substances. This action they exhibit even in close vessels. Thus a solution of grape sugar, mixed with potash, and left in a warm place, slowly forms a sour substance called *melassic acid*—while in cold lime-water the same sugar is gradually converted into another acid called the *glucic*. But in the air other acids are formed in the same mixtures, and the changes proceed, more rapidly. Such is the case also in the soil, where the elements of the air

and of water are generally at hand to favour the decomposition.

But the *nature* of the alcaline matter which is present determines also the rapidity with which such changes are produced. The most powerful alcaline substances —potash and soda—produce all the above effects most quickly; lime and magnesia are next in order, and the alumina of the clay soils, though much inferior to all these, is far from being without an important influence.

Hence one of the benefits which result from the use of wood-ashes containing carbonate of potash, when employed in small quantities and along with vegetable and animal manures, as they are in this country; but hence also the evil effects which are found to follow from the application of them in too large doses or too frequently repeated. Thus in countries where wood abounds, and where it is usual, as in Sweden and Northern Russia, to burn the forests and to lay on their ashes as manure, the tillage can be continued for a few years only. After two or three crops the land is exhausted, and must again be left to its natural produce.

SECTION VIII.—SPECIAL EFFECTS OF CAUSTIC LIME UPON THE SEVERAL VARIETIES OF ORGANIC MATTER IN THE SOIL.

The effects of lime upon organic matter are precisely the same in kind as those of alcaline substances in general. They are only less in degree, or take place more slowly, than when soda or potash is employed. Hence, the greater adaptation of lime to the purposes of practical agriculture.

1°. *Action of caustic lime alone upon vegetable matter.* —If the fresh leaves and twigs of plants, or blades and roots of grass, be introduced into a bottle, surrounded

with slaked lime, and corked—they will slowly undergo a certain change of colour, but they may be preserved for years without exhibiting any striking change of texture. If dry straw be so mixed with slaked lime, it will exhibit still less alteration. In either case also the changes will be even less perceptible if, instead of slaked lime, the *carbonate* (or *mild* lime), in any of its forms, be mixed with these varieties of vegetable matter. On some other varieties of vegetable matter,—such, for example, as are undergoing rapid decay, or have already reached an advanced stage of decomposition,—an admixture of slaked lime produces certain perceptible changes immediately, and mild lime more slowly, but these changes being completed, the tendency of *lime alone* is to arrest rather than to promote further *rapid* alterations. Hence, the following opinions of experienced practical observers must be admitted to be theoretically correct—in so far as they refer to *slaked lime acting alone*.

"If straw or long dung be mixed with slaked lime it will be preserved" (Morton).*

"Lime mixed in a mass of earth containing the live roots and seeds of plants will *not* destroy them" (Morton).†

"Sir H. Davy's theory, that lime dissolves vegetable matter, is given up; in fact, it hardens vegetable matter" (Mr. Pusey).‡

These opinions, I have said, are probably correct in so far as regards the unaided action of lime. They even express, with an approach to accuracy, what will take place in the interior of compost heaps of a certain kind, or in some very dry soils; but that they cannot apply to the ordinary action of lime upon the soil is proved by the

* *On Soils*, 3rd edition, p. 181.
† Ibid.
‡ *Royal Agricultural Journal*, iii., p. 212.

other result of universal observation, *that lime, so far from preserving the organic matter of the land to which it is applied, in reality wastes it*—causes, that is, or disposes it to disappear. It is unfortunate indeed that opinions such as those above quoted should be so generally or broadly expressed by practical men, as they tend to propagate erroneous impressions.

2°. *Action of caustic lime on organic matter in the presence of air and water.*—In the presence of air and water, when assisted by a favouring temperature, vegetable matter, as we have already seen, undergoes spontaneous decomposition. In the same circumstances lime promotes and sensibly hastens this decomposition—altering the forms or stages through which the organic matter must pass—but bringing about more speedily its final conversion into carbonic acid and water. During its natural decay in a moist and open soil, organic matter gives off a portion of carbonic acid gas, which escapes into the air, and forms at the same time certain other acids which remain in the dark mould of the soil itself. When quick or slaked lime is added to the land, its first effect is to combine with these acids—to form carbonate, humate, &c., of lime—till the whole of the acid matter existing at the time is taken up. That portion of the lime which remains uncombined, either slowly absorbs carbonic acid from the air or unites with the carbonate already formed, to produce the known compound of hydrate with carbonate of lime*—waiting in this state in the soil till some fresh portions of acid matter are formed with which it may combine. But it does not inactively wait; it persuades and influences the organic matter to combine with the oxygen of the air and of the water with which it is surrounded, for the production of such acid substances—till finally the whole of the lime be-

* That compound, namely, which is produced when quick-lime slakes spontaneously in the air.—See page 43.

comes combined either with carbonic acid or with some other acid of organic origin.

Nor at this stage are the action and influence of lime observed to cease. On the contrary, this result will, in most soils, be arrived at in the course of one or two years, while the beneficial action of the lime itself may be perceptible for twenty or thirty years. Hence there is much apparent ground for the opinion of Lord Kames, "that lime is as efficacious in its (so-called) effete as in its caustic state." Even the more strongly expressed opinion of the same acute observer, "that lime produces little effect upon vegetables till it becomes effete"—derives much support from experience—since lime is known to have comparatively little effect upon the productiveness of the land till one or two years after its application, and this period, as I have said, is in most localities sufficient to deprive even slaked lime of all its caustic properties.

Of the saline compounds* which caustic lime thus forms, either immediately or ultimately, some, like the carbonate and humate, being very sparingly soluble in water, remain more or less permanently in the soil; others, like the acetate of lime,† being readily soluble, are either washed out by the rains or are sucked up by the roots of the growing plants. In the former case they cause the removal of both organic matter and of lime from the land; in the latter they supply the plant with a portion of organic food, and at the same time with lime—without which, as we have frequently before remarked, plants cannot be maintained in their most healthy condition.

* Saline compounds or salts are always formed when lime, magnesia, potash, soda, &c., combine with acids.

† Acetate of lime consists of acetic acid or vinegar and lime.

SECTION IX.—ACTION OF MILD OR CARBONATE OF LIME UPON THE VEGETABLE MATTER OF THE SOIL.

The main utility of lime, therefore, after it has first removed the sourness it found in the soil,depends upon its prolonged *after*-action upon the vegetable matter. What is this action, and in what consist the benefits to which it gives rise?

In answering this question, it is of importance to observe that all the effects produced by alcaline substances in general—whether by lime or by potash—in the caustic state, are produced in *kind* also by the same substances in the state of carbonate. The carbonic acid with which they are united is retained by a comparatively feeble affinity, and is displaced with greater or less ease by almost every other acid compound which is produced in the soil. With this displacement is connected an interesting series of beautiful re-actions, which it is of consequence to understand.

The great end which nature, so to speak, has in view, in all the changes to which she subjects organic matter in the soil, is to convert it—with the exception of its nitrogen—into carbonic acid and water. For this purpose it combines, at one time, with the oxygen of the air, while at another it decomposes water and unites with the oxygen or the hydrogen which are liberated, or with both to form new chemical combinations. Each of these new combinations is either immediately preliminary to, or is attended by, the conversion of a portion of the elements of the organic matter into one or other of those simpler forms of matter on which plants live. Now during these preliminary or preparatory steps, acid substances, as I have already explained, are among others constantly produced. With these acids, the carbonate of lime, when present in the soil, is ever ready to combine. But, in so combining, it gives off the carbonic

acid with which it is already united, and thus a continual, slow, evolution of carbonic acid is kept up as long as any undecomposed carbonate remains in the soil.

I do not attempt to specify by name all the various acid substances which are thus formed during the oxidation of the organic matter, and which successively unite with the lime, because the entire series of interesting and highly important changes, which organic substances undergo in the soil, has as yet been too little investigated, to permit us to do more than speak in general terms of the nature of the chemical compounds which are most abundantly produced. Of two facts, however, in regard to them, we are certain—that they are simpler in their constitution than the original organic matter itself, from which they are derived—and that they have a tendency to assume still simpler forms, if they continue to be exposed to the same united action of air, water, and alcaline substances.

Hence the compounds which lime has formed with the acid substances of the soil, the humate, ulmate, &c., themselves hasten forward to new decompositions,—unite with more oxygen, liberate slowly portion after portion of their carbon in the form of carbonic acid, and of their hydrogen in the form of water—till at length the lime itself is left again in the state of carbonate, or in union with carbonic acid only. This residual carbonate of lime begins again the same round of changes through which it had previously passed. It gives up its carbonic acid at the bidding of some more powerful organic acid produced in its neighbourhood, while this acid, by exposure to the due influences, undergoes new alterations till it also is finally resolved into carbonic acid and water.

Two circumstances deserve to be borne in mind in reference to these successive decompositions—*first*, that as they proceed, more soluble compounds of lime are now and then formed, some of which are washed out by

the rains and escape from the soil, while others minister to the growth of plants;—and *second*, that very much carbonic acid is produced as their final result—of which also part is taken up by the roots of plants, and part escapes into the air. Thus at every successive stage a portion of organic matter is lost to the soil. If this quantity be greater than that which is yearly gained in the form of roots or decayed leaves and stems of plants, or of manure artificially added, the soil will be gradually exhausted—if less, it will every year become more rich in vegetable matter.

It is also to be borne in mind that although, for the purpose of illustration, I have supposed the carbonate of lime first formed in the soil to be subsequently combined with other acids, which gradually decompose and leave it again in the state of carbonate,—yet it will rarely happen that the whole of the carbonate of lime in the soil will be brought at one and the same time, into any of these new states of combination. In general a part of it only is thus at any one time employed in working up the acid substances produced. But it is necessary that it should be universally diffused through the soil in order that it may be every where at hand to perform the important part of its functions above explained. It is only where little lime is present, or where decaying vegetable matter is in exceeding abundance, that the whole of the carbonate can at one and the same time disappear.

SECTION X.—SUMMARY OF THE CHEMICAL CHANGES WHICH LIME AND ORGANIC MATTER MUTUALLY UNDERGO IN THE SOIL.

The changes, therefore, which lime and organic matter, supposed to be free from nitrogen, respectively undergo, and their mutual action in the soil, may be summed up as follows:—

1°. The organic matter, under the influence of air and moisture, spontaneously decomposes, and besides carbonic acid which escapes, forms also other acid substances which linger in the soil.

2°. With these acids the quick-lime combines and either by its union with them or with carbonic acid from the air gradually loses its caustic state.

3°. The production of acid substances by the oxidation of the organic matter—goes on more rapidly under the pre-disposing influence of the lime, whether caustic or carbonated. These acids combine with the lime, liberating from it, when in the state of carbonate, a slow but constant current of carbonic acid, upon which plants at least partly live.

4°. The acid organic matter which thus unites with the lime continues itself to be acted upon by the air and water, aided by heat and light—itself passes through a succession of stages of decomposition, at each of which it gives off water or carbonic acid, retaining still its hold of the lime—till at last being wholly decomposed it leaves the lime again in the state of carbonate ready to begin anew the same round of change.

5°. During this series of progressive decompositions, certain more soluble compounds of lime are formed, by which plants are in part at least supplied with this earth, and the production of which enables the rains to carry off both lime and organic matter from the soil.

And, again, the more rapid the production of the acid substances which result from the union of the organic matter with oxygen, the more abundant in general also is the production of those gaseous and volatile compounds which it forms by uniting with hydrogen—so that, in promoting the formation of the one class of bodies lime also favours the evolution of the other in greater abundance, and thus in a double measure contributes to the exhaustion of the soil.

The *disposing* action of lime to this twin form of decomposition, few varieties of organic matter can resist —and hence arises the well known efficacy of lime in resolving and rendering useful the apparently inert vegetable substances that not unfrequently exist in the soil.

SECTION XI.—OF THE COMPARATIVE UTILITY OF BURNED AND UNBURNED LIME.

Is there no advantage, then, we may ask, in using caustic or burned rather than carbonated or unburned lime? If the ultimate effects of both upon the land be the same, why be at the expense of burning? Among other benefits arising from the use of burned lime may be enumerated the following:—

1°. By burning and slaking, the lime is reduced to the state of an impalpable powder, finer than could be obtained by any available method of crushing. It can in consequence be diffused more uniformly through the soil, and hence a smaller quantity will produce an equal effect. This minute state of division also promotes in a wonderful degree the chemical action of the lime. In all cases chemical action takes place between exceedingly minute particles of matter, and among solid substances the action is more rapid the finer the powder to which they can be reduced. Thus a mass of iron or lead slowly rusts or tarnishes in the air, but if the mass of either metal be reduced to the state of an impalpable powder—which can be done by certain chemical means —it will take fire when simply exposed to the air at the ordinary temperature, and will burn till it is entirely converted into oxide of iron or oxide of lead. By mere mechanical division the apparent action of the oxygen of the air upon metals is augmented and hastened in this extraordinary degree—and a similar

heightening of the chemical influence of lime takes place when it is brought in an impalpable state into contact with the vegetable matter upon which it is intended to act.

2°. The effect of burned lime is more powerful and more immediate than that of unburned lime in the form of chalk, marl, or shell sand. Hence it sooner neutralizes the acids which exist in the soil, and sooner causes that decomposition of vegetable matter of every kind to commence, upon which its efficacy, in a great degree, depends. Hence, when it can easily be procured, it is better fitted for sour grass or arable lands, for such as contain an excess of vegetable matter, and especially for such as abound in that dead or inert form of organic matter which requires a stronger stimulus—the presence of more powerful chemical affinities, that is—to bring it into active decomposition. In such cases, the lime has already done much good before it has been brought into the mild state—by exposure in the soil—and remaining afterwards in this state in the soil, it still serves, in a great measure, the same slower after-purposes, as the original addition of carbonate would have done.

3°. Besides, if any portion of it, after the lapse of two or three years, still linger in the caustic state, it will continue to provoke more rapid changes among the organic substances in the soil, than mild lime alone could have done.

4°. Further, quick-lime is soluble in water, and hence every shower that falls and sinks into the soil carries with it a portion of lime, so long as any of it remains in the caustic state. It thus reaches acid matters that lie beneath the surface, and alters and ameliorates even the subsoil itself.

5°. It is not a small additional recommendation of quick-lime, that limestone, by burning, loses about 44

per cent. of its weight—chiefly carbonic acid—thus enabling nearly twice the quantity of lime to be conveyed from place to place at the same cost of transport. This not only causes a direct saving of money—as when the burned chalk of Antrim is carried by sea to the Ayrshire coasts—but an additional saving of labour also upon the farm—where the number of hands and horses is often barely sufficient for the necessary work.

APPENDIX TO CHAPTER VI.

As in the preceding chapter I have made frequent use of the words carbon, hydrogen, oxygen, and water, and as in the following chapter I shall have occasion to speak also of ammonia and nitric acid, I here introduce an extract from my *Catechism of Agricultural Chemistry and Geology*, which will explain the nature and properties of the substances to which these several names are given, and their composition, when they consist of more than one substance. The preparation and properties of carbonic acid have already been explained in pages 2 and 3.

Q. *What is carbon?*

A. Carbon is a solid substance, usually of a black colour, which has no taste or smell, and burns more or less readily in the fire. Wood-charcoal, lamp-black, coke, black-lead, and the diamond, are varieties of carbon.

The teacher will here exhibit a piece of charcoal and show how it burns in the fire, or in the flame of a candle. He may also draw the attention of his pupils to the remarkable difference in appearance between charcoal and the diamond, though their substance is essentially the same.

Q. *What is hydrogen?*

A. Hydrogen is a kind of air or gas which burns in the air as

Fig. 2.

coal gas does, but in which a candle will not burn, nor an animal live. When mixed with common air, it will explode if brought near the flame of a candle. It is also the lightest of all known substances.

Here the teacher will take a beer or champaign glass (fig. 2), will put into it some pieces of zinc or iron filings, and pour over them a small quantity of oil of vitriol (sulphuric acid) diluted with twice its bulk of water, and then cover the glass for a few minutes. On putting in a lighted taper, an explosion will take place. He will then repeat the same experiment in a phial, into the cork of which he has introduced a common gas jet or a bit of a clay tobacco pipe (fig. 3.) After a short time, when the hydrogen gas produced has driven out all the common air from the bottle, a light may be applied to the jet, when the gas will take fire and burn. The cork and jet may now be taken out of the bottle, and a lighted taper introduced into it, when the taper will be extinguished, while the gas itself will take fire and burn at the mouth of the bottle. Lastly, if the teacher possesses a small balloon, he may fill it with the gas by attaching it to the mouth of the bottle, and may thus show that the gas is so light that it will carry heavy bodies up with it through the air.

Fig. 3.

Fig. 4.

Q. *What is oxygen?*

A. Oxygen is also a kind of air or gas. A candle burns in it with great brilliancy; animals also live in it; and it is heavier than hydrogen gas or common air. It forms one-fifth of the bulk of the air we breathe.

The teacher will here exhibit a bottle of oxygen gas (fig. 4), and show how rapidly and brilliantly a lighted taper burns when introduced into it.

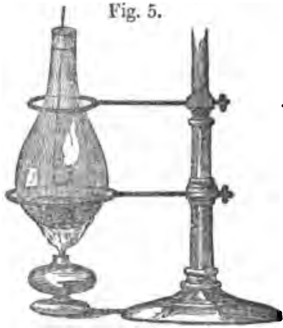
The least troublesome mode of preparing oxygen gas is to rub together in a mortar equal weights of oxide of copper and chlorate of potash, to put the mixture into a common Florence flask, and to apply the lamp as in fig. 5.

Oxide of copper is prepared by heating a piece of sheet copper or a penny piece to redness in the fire, allowing it to cool, and then striking it with a hammer, when scales of oxide of cop-

per fall off. The oxide employed in the preparation of the gas may be washed out of the flask, and employed again for any number of times.

When prepared in this way the properties of the gas may be shown in the flask by introducing a lighted taper or a bit of red-hot charcoal at the end of a wire. Or if the teacher wish to collect a bottle of the gas, he may do so by fitting a bent tube and cork into the mouth of the flask, and collecting it over water, in the same way as when a retort is used, see fig. 7.

Fig. 5.



A very elegant method of preparing the gas is to put a few grains of *red oxide of mercury* into the bottom of a test tube, and to apply the heat of the lamp. Oxygen will be given off—as can be shown by putting into the tube a half-kindled match, and showing how rapidly it burns up—while metallic mercury will distil off in minute brilliant globules. This experiment the teacher may use to illustrate the meaning of the word *oxide*.

Fig. 6.

Q. *What is nitrogen?*

A. Nitrogen is also a kind of air, but is different from both the other two. *Like* hydrogen, a taper will not burn nor will an animal live in it, but *unlike* hydrogen, it does not take fire when brought near the flame of a candle. It is a little lighter than atmospheric air.

The teacher will here exhibit a bottle of this gas and show that a lighted taper is extinguished, when introduced into it. (Fig. 6.)

Fig. 7.

The easiest mode of preparing nitrogen is by mixing together a quantity of sal ammoniac with half its weight of saltpetre, both in fine powder, and heating them in a retort over a lamp. The gas which comes off is collected over water, see fig. 7.

Q. *Do oxygen and nitrogen exist in the air we breathe?*

A. Yes. Five gallons of air contain one gallon of oxygen, and nearly four gallons of nitrogen.

Q. *Of what does water consist?*

A. Water consists of oxygen and hydrogen.

Q. *How much of each of these elements is contained in water?*

A. Every 9 lbs. of water contains about 8 lbs. of oxygen and 1 lb. of hydrogen.

The teacher may here draw the attention of his pupils to the very remarkable circumstance, that liquid water, which puts out all fire, should consist of two gases, one of which (hydrogen) burns readily, while in the other (oxygen) bodies burn with great brilliancy.

Q. *What is ammonia?*

A. Ammonia is a kind of air which has an exceedingly strong smell, and possesses alcaline properties. The common hartshorn of the shops is merely water impregnated with this gas.

Here the teacher may exhibit a bottle of hartshorn or of smelling salts *(carbonate of ammonia)*, and make his pupils acquainted with the smell of ammonia. He may likewise show that hartshorn restores the blue colour to vegetable blues that have been reddened by an acid, and is therefore alcaline.

The teacher may also at this stage take the opportunity of examining his pupils on the properties of *all the six* kinds of air described in the Catechism—namely, hydrogen, oxygen, nitrogen, chlorine, carbonic acid, and ammonia. He may ask in what properties they agree—in what they differ from each other, and so on.

Q. *Under what circumstances is ammonia produced naturally?*

A. It is produced in fermenting compost or manure heaps, and in fermenting urine, and it is the cause of the smell perceived in hot stables.

Q. *How can you detect the presence of this ammonia?*

A. By dipping a rod or feather in vinegar, and holding it over the dung heap or in the stable, when, if ammonia is present in the air, white fumes will become visible.

The teacher will show this experiment by dipping a glass rod or feather into vinegar, or into muriatic acid, and holding it over the mouth of his hartshorn bottle, when white fumes will become visible, showing that ammonia is escaping from the bottle in the form of gas.

Q. *What does ammonia consist of?*

A. Ammonia consists of the two gases, nitrogen and hydrogen.

14 lbs. of nitrogen and 3 lbs. of hydrogen make 17 lbs. of ammonia.

Q. *How does this ammonia enter into the roots of plants, when it is formed in the manure?*

A. It is dissolved in the soil by water, and is then sucked in by the roots.

Q. *What substances are formed in plants by the aid of this ammonia?*

A. The gluten and other substances containing nitrogen are formed in part by the aid of this ammonia.

Q. *Is this ammonia, then, a very important ingredient in manure?*

A. Yes. Because nitrogen, in some shape or other, is absolutely necessary to the growth of plants.

Q. *What is nitric acid?*

A. Nitric acid is a very sour corrosive liquid, called also aquafortis. It consists of the two gases, nitrogen and oxygen.

14 lbs. of nitrogen and 40 lbs. of oxygen form 54 lbs. of dry nitric acid.

As properties which distinguish liquid nitric acid, it may be shown—1°. That it stains the fingers yellow. 2°. That when poured upon a bit of copper (a halfpenny), it becomes hot and of a deep-blue colour, and gives off red fumes. 3°. That when poured upon sugar or starch and heated, the same red fumes appear. In this latter case, oxalic acid is formed.

Q. *What is nitrate of soda?*

A. Nitrate of soda is a white salt-like (saline) substance, which is found in the earth in some parts of Peru, and is often applied with great advantage as a top-dressing to grass lands and to young corn.

To show the difference between nitrate of soda and common salt, with which it is often adulterated, sprinkle a little of each on a red hot cinder. The common salt will crackle and leap in the fire *(decrepitate)*, while the nitrate of soda will cause a bright flame or burning *(deflagration)*. Saltpetere (nitrate of potash) will deflagrate like nitrate of soda, but if there be much common salt present in either of the nitrates it will first *decrepitate* and then *deflagrate*.

Q. *What does nitrate of soda consist of?*

A. It consists of nitric acid and soda.

54 lbs. of nitric acid and 31 lbs. of soda form 85 lbs. of nitrate of soda.

The teacher may take this opportunity of verbally explaining the kind of terms by which chemists denote combinations of the nitric, sulphuric, phosphoric, and carbonic acids with potash, soda, lime, and magnesia,—that when carbonic acid combines with any of these substances it forms a carbon*ate*, phosphoric acid a phosph*ate*, sulphuric acid a sulph*ate*, nitric acid a nitra*ate*. Hence, that ***phosphate of lime*** denotes a combination of phosphoric acid with lime, ***sulphate of soda*** a combination of sulphuric acid with soda, and so on.

CHAPTER VII.

Theory of the action of lime continued. Action of lime on organic substances containing nitrogen. Production of nitric acid and ammonia. How the chemical changes produced by lime upon organic matter directly benefit vegetation. Why lime should be kept near the surface. Action of lime upon the inorganic or mineral matter of the soil. Its action upon salts of iron, magnesia, alumina, and soda, in the soil.

SECTION I.—ACTION OF LIME ON ORGANIC SUBSTANCES WHICH CONTAIN NITROGEN—PRODUCTION OF NITRIC ACID AND AMMONIA.

I have hitherto, for the sake of simplicity, treated only of the action, whether immediate or remote, which is exercised by lime upon organic matter supposed to contain no nitrogen. Its action upon compounds in which nitrogen exists is no less beautiful and simple, perhaps even more intelligible and more obviously useful to vegetation.

There are several well-known facts which it is here of importance to consider—

1°. That the black vegetable matter of the soil always contains nitrogen. Even that which is most inert retains a sensible proportion of it. It exists in dry peat to the amount of about 2 per cent. of its weight, and still clings to the other elements of the organic matter, even after it has undergone those prolonged changes by which it is finally converted into coal. Since nitrogen, therefore, is so important an element in all vegetable food, and so necessary in some form or other to the healthy growth and maturity of plants, it must be of consequence to awaken this element of decaying veget-

able matter, when it is lying dormant, and to cause it to assume a form in which it can enter into and become useful to our cultivated plants.

2°. That if vegetable matter of any kind be heated with slaked lime, the whole of the nitrogen it may contain, in whatever state of combination it may previously exist, will be given off in the form of ammonia. The same takes place still more easily if a quantity of caustic potash or caustic soda be mixed with the caustic lime. Though it has not as yet been proved by direct experiment—yet I consider it to be exceedingly probable that what takes place quickly in our laboratories, at a comparatively high temperature, may take place more slowly also in the soil, and at the ordinary temperature of the atmosphere.

3°. That when animal and vegetable substances are mixed with earth, lime, and other alcaline matters, in the so-called nitre beds,* ammonia and nitric acid are both produced, the quantity of nitrogen contained in the weight of these compounds extracted being much greater than was originally present in the animal and vegetable matter employed (Dumas). Under the influence of alcaline substances, therefore, *even when not in a caustic state*, the decay of animal and vegetable matter in the presence of air and moisture causes some of the nitrogen of the atmosphere to become fixed in the soil in the form of ammonia or of nitric acid. What takes place on the confined area of a nitre bed happens without doubt in our lime composts, and may take place to some extent also in the wider area of a well-limed and well-manured field.

In the action of alcalies in the nitre bed, *disposing* to the production of nitric acid, we observe the same kind

* The nitre beds of the continent of Europe are in reality large compost heaps, which are turned over and washed once or twice a year. The washings when boiled down yield saltpetre.

of agency, which we have already attributed to lime, in regard to the more abundant elements which exist in the vegetable matter of the soil. It gently persuades all the elements—nitrogen and carbon alike—to unite with the oxygen of the air and with that of water, and thus ultimately to form acid compounds with which it may itself combine.

The action of lime upon such organic matters containing nitrogen as usually exist in the soil, may, therefore, be briefly stated as follows :—

1°. These substances, like all other organic matter, undergo in moist air—and, therefore, in the soil—a spontaneous decomposition, the general result of which is the production of ammonia, and of an acid substance with which the ammonia may combine. This change is precisely analagous to that which takes place in such substances as starch and vegetable fibre, which contain no nitrogen. In each case one portion of the elements of the organic substance unites with oxygen to produce an acid, the other portion with hydrogen to form one or more compounds possessed of alcaline or indifferent properties. Thus—

		With oxygen	With hydrogen
Vegetable matter	produces	Carbonic, ulmic, and other acids.	Marsh gas or other carburetted hydrogens.
Animal matter	produces	Carbonic, *nitric*, ulmic, and other acids.	Ammonia.

If the ammonia happen to be produced in larger relative quantity than the acids with which it is to combine, or if the carbonic be the only acid with which it has the opportunity of uniting, a portion of it may escape into the air. This rarely happens, however, in the soil—the absorbent properties of the earthy matters of which the soil consists being in most cases sufficient to retain the ammonia, till it can be made available to the purposes of vegetable life.

When caustic lime is added to a soil in which ammonia exists in this state of combination with acid matter, it seizes upon the acid and sets the ammonia free. This it does with comparative slowness, however—for it does not at once come in contact with the whole of the ammonical matter. It does so by degrees, therefore, so as to store up the ammonia in the pores of the soil till the roots of plants can reach it, or till it can itself undergo a further change by which its nitrogen may be rendered more fixed.

Carbonate of lime, on the other hand, still more slowly persuades the ammonia to leave the acid substances (ulmic, nitric? &c.), with which it is combined, and yielding to it in return its own carbonic acid, enables it in the state of soluble carbonate of ammonia to become more immediately useful to vegetation.

2°. But in undergoing this spontaneous decay even substances containing nitrogen reach at length a point at which decomposition appears to stop—an inert condition in which, though nitrogen be present in them as it is in peat, they cease sensibly to give it off in such a form or quantity as to be capable of ministering to vegetable growth. Here caustic lime steps in more quickly, and mild lime by slower degrees, to promote the further decay. It induces the carbonaceous matter to take oxygen from the air and from water and to form acids, and the nitrogen to unite with the hydrogen of the water for the production of ammonia—thus helping forward the organic matter in its natural course of decay, and enabling it to fulfil its destined purposes in reference to vegetable life.

3°. But the ammonia which is thus disengaged in the soil by decaying organic matter, though not immediately worked up, so to speak, by living plants, is not permitted to escape in any large quantity into the air. The soil, as I have already stated, is usually absorbent enough to retain it in its pores for an indefinite period

of time. And as in nature and upon the earth's surface the elements of matter are rarely permitted to remain in a state of repose, the ammonia, though retained apparently inactive in the soil, is yet slowly uniting with a portion of the surrounding oxygen* and forming nitric acid. When no other *base* is present, this nitric acid, as it is produced, unites with some of the ammonia itself which still remains, forming *nitrate of ammonia*—but if soda, or potash, or lime be present within its reach, it unites with them in preference, and forms *nitrate of soda, nitrate of potash, or nitrate of lime.*

But lime, if present, is not an inactive spectator, so to speak, of this slow *oxidation* of ammonia. On the contrary, it promotes this final change, and by being ready to unite with the nitric acid as it forms, increases and accelerates its production, at the expense of the ammonia which it had previously been instrumental in evolving.

4°. One other important action of lime, by which the same compounds of nitrogen are produced in the soil, may in this place be most properly noticed. It is a chemical law of apparently extensive application, that, when one elementary substance is undergoing a direct chemical union with a second *in the presence of a third* substance, a tendency is imparted to the third to unite also with one or with both of the other two, although in the same circumstances it would not unite with either, if present alone. Thus, when the carbonaceous matter of the soil is undergoing oxidation in the air—that is, combining with the oxygen of the atmosphere—it imparts a tendency to the nitrogen also of the air to unite with oxygen, which when mixed with that gas alone†

* Nitric acid consists of nitrogen and oxygen. Water consists of hydrogen and oxygen. Ammonia consists of nitrogen and hydrogen. When ammonia combines with, or is oxidised by, the oxygen of the atmosphere, its hydrogen forms water, while its nitrogen produces nitric acid.

† The atmosphere consisting, as the reader will recollect, of nitrogen and oxygen.

it has no known disposition to do. The result of this is the production of a small, and always a variable, proportion of nitric acid during the decomposition in the soil of organic matter which itself contains no nitrogen.

Again, it is an equally remarkable chemical law that elementary bodies which refuse to combine, however long we may keep them together in a state of mixture, will yet unite readily when presented to each other in what is called by chemists the *nascent* state—that is, at the moment when one or other of them is produced or is separated from a previous state of combination.

Thus when the organic matter of the soil decomposes water in the presence of atmospheric air, its carbon unites with the greater part of the oxygen and hydrogen which are set at liberty, and at the same time with more or less of the oxygen of the atmosphere—but at the same instant the nitrogen of the atmosphere, which is everywhere present, seizes a portion of the hydrogen of the water, and forms ammonia. Thus a variable, and in any one limited spot, a minute, but over the entire surface of the globe, a large quantity of ammonia is produced during the oxidation even of the purely carbonaceous portion of the organic matter of the soil.

Now in proportion as the presence of lime promotes this decay of vegetable and other organic matter in the soil—in the same proportion does it promote the production of ammonia and nitric acid, at the expense of the free nitrogen of the atmosphere, and this may be regarded as one of the valuable and constant purposes served by the presence of calcareous matter in the soil.

SECTION II.—HOW THE CHEMICAL CHANGES PRODUCED BY LIME UPON ORGANIC MATTER DIRECTLY BENEFIT VEGETATION.

The reader may not enquire how all these interesting chemical changes in the organic matter which attend

upon the presence of lime in the soil are directly useful to vegetation, and yet it may be useful shortly to answer the question.

1°. Lime combines with the acid substances already existing in the soil, and thus promotes the decomposition of vegetable matter which those acid substances arrest. The further decompositions which ensue are attended at every step by the production either of gaseous compounds—such as carbonic acid and light carburetted hydrogen*—which are more or less abundantly absorbed by the roots and leaves of plants, and thus help to feed them—or of acid and other compounds, soluble in water, which, entering by the roots, bear into the circulation of the plant not only organic food but that supply of lime also which healthy plants require.

2°. The changes it induces upon substances in which nitrogen is present are still more obviously useful to vegetation. It sets free ammonia from the compounds in which it exists already formed, and promotes its slow conversion into nitric acid, by which the nitrogen is rendered more fixed in the soil. It disposes the nitrogen of more or less inert organic matter to assume the forms of ammonia and nitric acid, in which states experience has long shown that this element is directly favourable to the growth of plants. And

3°. It influences, in an unknown degree, the nitrogen of the atmosphere to become fixed in larger proportion in the soil, in the form of nitric acid and ammonia, than would otherwise be the case, and this it does both by the greater amount of decay or oxidation which it brings about in a given time, and by the *kind* of compounds which, under its influence, the organic matter is persuaded to form. The amount of nitrogenous food

* Light carburetted hydrogen or marsh gas consists of carbon and hydrogen.

placed within reach of plants by this agency of lime will vary with the climate, with the nature of the soil, with its condition as to drainage, and with the more or less liberal and skilful manner in which it is farmed.

SECTION III.—WHY LIME SHOULD BE KEPT NEAR THE SURFACE.

The considerations presented in the preceding sections suggest important reasons why lime should be kept near the surface of the soil—since

1°. The action of lime upon organic matter is almost nothing in the absence of air and moisture. If the lime sink, therefore, beyond the constant reach of fresh air, its efficacy is in a great degree lost.

2°. But the agency of the light and heat of the sun, though I have not hitherto specially insisted upon their action—are scarcely less necessary to the full experience of the benefits which lime is capable of conferring. The light of the sun accelerates nearly all the chemical decompositions that take place in the soil—while some it appears especially to promote. The warmth of the sun's rays may penetrate to some depth, but their light can only act upon the immediate surface of the soil. Hence the skilful agriculturist will endeavour, if possible, to keep some of his lime at least upon the very surface of his arable land. Perhaps this influence of light might even be adduced as an argument in favour of the frequent application of lime in small doses, as a means of keeping a portion of it always within reach of the sun's rays; and this more especially on grass lands, to which mechanical means can with difficulty be applied for the purpose of bringing again to the surface the lime that has sunk.

There are, at the same time, good reasons also why

a portion of the lime should be diffused through the body of the soil, both for the purpose of combining with organic acids already existing there, and with the view of acting upon certain inorganic or mineral substances, which are either decidedly injurious, or by the action of lime may be rendered more wholesome to vegetation.

In order that this diffusion may be effected, and especially that lime may not be unnecessarily wasted where pains are taken by mechanical means to keep it near the surface, an efficient system of under-drainage should be carefully kept up. Where the rains that fall are allowed to flow off the surface of the land, they wash more lime away the more carefully it is kept among the upper soil—but where a free outlet is afforded to the waters beneath, they carry the lime with them as they sink towards the subsoil, and may have been robbed again of the greater part of it before they escape into the drains. Thus on drained land the rains that fall aid lime in producing its beneficial effects, while in undrained land they in a greater or less degree counteract it.

SECTION IV.—ACTION OF LIME UPON THE INORGANIC OR MINERAL MATTER OF THE SOIL.

I have hitherto spoken only of the action of lime upon the purely organic part of the soil—that which contains only carbon, hydrogen, oxygen, and nitrogen. But its operation in regard to the inorganic substances contained in the soil is no less important.

1°. *The decaying vegetable matter* in the stems, roots, and leaves of plants, which form the so-called humus of the soil, contain a large proportion of the inorganic matter which was necessary to their existence in the living

state. As they decompose, this inorganic matter is liberated. By promoting this decomposition, therefore, lime sets free this mineral matter, and provides at once abundant organic and inorganic food to the growing plant. This result of the action of lime is no less important in reference to its fertilizing quality than that by which it causes the production of those numerous changes in the purely organic matter of the soil to which I have already adverted.

If the vegetable matter decay rapidly, it will supply in abundance all the materials, both organic and inorganic, which new races of plants require to form their entire substance. If it be in an inert state or decompose slowly, the food it contains remains locked up and comparatively useless to vegetation. In quickening the decay of this inert or slowly decomposing matter, it is easy to see, therefore, how lime should render the land more fertile, and should do so more sensibly where vegetable matter is more abundant.

2°. *The mineral and rocky fragments* in the soil are acted upon in a similar manner.

Among the earthy constituents of soils there often exist fragments of felspar and other minerals derived from the granitic and trap rocks, as well as portions of the slaty and other beds from which the soils have been formed (p. 75), and which, as they crumble down, yield more and more of those inorganic substances on which plants live.

The decomposition of these minerals and rocks proceeds more or less rapidly under the conjoined action of the oxygen, the carbonic acid, and the moisture of the atmosphere. But the presence of lime promotes this decomposition, and the consequent liberation of the inorganic substances which the rocks contain.

The silicates of potash and soda are among the most important compounds which these minerals and rocky

fragments contain. These silicates, after being heated to redness with quick-lime, readily yield a portion of their potash or soda to water poured upon the mixture. The same result follows, but more slowly, when, without being heated, they are mixed together into a paste with water, and left for a length of time at the ordinary temperature of the atmosphere. It is reasonable, therefore, to suppose that in the soil of our fields a similar decomposition will slowly take place when quick-lime is mixed with it. It will take place, also, though still more slowly, when lime is added in the form of carbonate.

By some the liberation of potash and soda in this way is supposed to be the most important action exercised by lime in rendering the land more productive. With this extreme opinion I do not agree, though it must be conceded, I think, that in numerous instances a certain amount of benefit must follow from the chemical action it is thus fitted to exercise.

I have spoken of lime as liberating the inorganic constituents of the decaying vegetable matter of the soil. The stalks of the grasses and the straw of our corn-bearing plants also contain silicates of potash and soda, which lime sets free in hastening the decomposition of the vegetable matter of which they form a part. Besides liberating, it further decomposes these silicates, as it does those of the minerals in the soil, and sets their potash and soda free to perform those important functions they are known to exercise in reference to the growth of plants. I am inclined to consider this part of the action of lime as of nearly equal importance to vegetation in many instances, with that which it exercises upon the mineral silicates.

While the potash or soda is set free in a soluble state, the lime unites with a portion of silica forming a silicate of lime, of which traces are to met with in nearly all soils. This silicate again is slowly decomposed by the

agency of the carbonic acid of the atmosphere, as I have already explained when speaking of this compound as one of the causes of the known fertility of soils formed from the decay of trap rocks (p. 78).

3°. Potash and soda exist sometimes in considerable quantity in our stiff clay soils in combination with the silica and alumina, of which they chiefly consist. From their extreme tenacity the air is in a great measure excluded from these soils, and hence chemical decomposition proceeds in them very slowly. The addition of lime alters their physical character, and by making them more open, admits the air, and thus promotes its decomposing action upon them. But it acts chemically also, in the same way as it does upon the silicates already spoken of, and thus compels them to give up more freely to the roots of plants those mineral substances by which their growth is to be made more luxuriant.

SECTION V.—ACTION OF LIME ON SALTS OF IRON, MAGNESIA, ALUMINA, AND SODA, WHEN CONTAINED IN THE SOIL.

1°. *Salts of Iron.*—Lime, either in the mild or in the caustic state, possesses the property of decomposing the sulphate and other saline compounds of iron, which especially abound in moorish and peaty soils, and in many localities so saturate the subsoil as to make it destructive to the roots of plants. Sprengel mentions a case in which the first year's clover always grew well, while in the second year it always died away. This, upon examination, was found to be owing to the ferruginous nature of the subsoil, which caused the death of the plants as soon as the roots began to enter into it.

When land is rendered unproductive by the presence of salts of iron, a dressing with lime will bring the land

into a wholesome state without other aid than those of the drain and the subsoil plough. If sulphate of iron be the cause of the evil the lime will combine with the acid, and form gypsum (sulphate of lime), while the *first* oxide of iron which is set free will, by exposure to the air, be converted into the *second* or red oxide, in which state this metal is no longer hurtful to vegetation.

The drain and the subsoil plough are useful auxiliaries to the lime in lessening the injurious effects of the compounds of iron, because they allow the rains to descend and gradually to wash away the noxious matter which has accumulated in the under soil—because they permit the descending water to carry with it portions of the lime in a state of solution, and thus to spread its good effects over the whole soil—and because they admit successive supplies of air as deep as the bottom of the drains, by which, while the action of the lime is promoted, those other good effects also are produced which the oxygen of the atmosphere can alone accomplish. In fact, unless an outlet for the surface water be thus provided beneath, by which the lime may be enabled to descend and the rains to wash away slowly the noxious substances from the subsoil, even the addition of a copious dose of lime will only produce a temporary improvement.

2°. *Salts of magnesia and alumina.*—Lime decomposes also the sulphates of magnesia and of alumina, both of which, but especially the former, are occasionally found in the soil in too large proportions, and, being very soluble salts, are liable to be taken up by the roots in such quantity as to be hurtful to growing plants. With the sulphuric acid of these salts the lime forms gypsum, as it does with the acid of sulphate of iron when present in a soil to which it is added—besides removing the evil effects of these very soluble sulphates, therefore, it exercises the beneficial action which gypsum is known to exhibit upon many of our cultivated crops.

Alumina has the property of combining readily with many vegetable acids, and in the clay soils exercises a constant influence—though more feeble in degree than that of lime—in persuading organic matter to those forms of decay in which acid compounds are more abundantly produced. Hence, clay soils almost always contain a portion of alumina in combination with organic matter. These organic compounds are decomposed by lime, and by the more energetic action of this substance their constituents are sooner made available to the wants of new races of plants.

3°. *Common salt and sulphate of soda.*—I shall bring under your notice only one other, but a highly important, decomposing action, which lime exercises in soils that abound in vegetable matter. In the presence of decaying organic substances the carbonate of lime is capable of slowly decomposing common salt, producing carbonate of soda and chloride of calcium. It exercises also a similar decomposing effect, even upon the sulphate of soda, and according to Berthollet,* incrustations of carbonate of soda† are observed on the surface of the soil, *wherever carbonate of lime and common salt are in contact with each other*. If we consider that along all our coasts common salt may be said to abound in the soil, being yearly sprinkled over it by the salt sea winds, we may safely conclude, I think, that the decomposition now explained must take place extensively in all those parts of our island which are so situated, if lime in any of its forms either exist naturally or has been artificially added to the land. The same must be the case also in those districts where salt springs occur,

* Dumas *Traite de Chemie*, ii., p. 334.

† Of *Trona* or *Natron*, which is what is called a *sesqui* carbonate of soda—containing one-half more carbonic acid than the common soda of the shops.

and generally over the new red sand-stone formation, in which sea salt more especially occurs.

And if we further consider the important purposes which the carbonate of soda thus produced may serve in reference to vegetation—that it may dissolve vegetable matter and carry it into the roots—that it may form soluble silicates, and thus supply the necessary siliceous matter to the stems of the grasses and other plants—and that rising, as it naturally does, to the surface of the soil, it there, in the presence of vegetable matter, provokes to the formation of nitrates, so wholesome to vegetable life—we may regard the decomposing action of lime by which the carbonate is produced from common salt, as in many localities fully equal in importance to that by which it liberates alcaline matter from the mineral silicates or from those which exist in the parts of plants.

CHAPTER VIII.

Of the exhausting effects of lime. How lime exhausts the land. Does lime necessarily exhaust the land? Ought the use of lime ever to be forbidden, or ought it to be resumed, continued, and only regulated? Clauses in agreements regarding lime and manure.

SECTION I.—OF THE EXHAUSTING EFFECTS OF LIME.

Several important facts in regard to what may be called the historical action of lime are familiar to practical men. Thus—

1°. When lime is applied to the land for the first time it produces a remarkably fertilizing effect.

2°. This effect continues for many years—the land yielding frequent crops of corn or long years of rich pasture without any addition of manure.

3°. New doses of lime renew its fertility again as it begins to flag, but each successive dose must be larger than the former to produce an equal effect.

4°. But at last the crops begin to fail beyond the power of lime to restore them. New additions of lime produce no sensible effect, and thus the use of lime is sometimes given up as a waste of money in one district while the practice is vigorously prosecuted in another.

"An overdose of marl," says Lord Kames, "produces for a time large crops, but at last renders the soil incapable of bearing either corn or grass, of which there are many examples."

In the district of the Isere in France, a tract of country which produced in its natural state no grain but rye, and yielded only three returns of the seed—grew

wheat readily when marled, and gave eight returns for the seed. Eight returns of wheat instead of three returns of rye! But, after forty years marling, it yields now only four returns of wheat. It continues to grow the more valuable grain, but the crops are only one-half their original bulk.

The same is true of lime in all its forms. And when land is brought into this condition, even rich manure scarcely succeeds, after years of carefully restorative treatment, in bringing the soil back again to its former productive condition.

Hence the proverb, which has obtained a place in almost every European language—*Lime enriches the fathers and impoverishes the sons.*

Two questions naturally arise in reference to this result.

How does lime cause the land to become exhausted?

Is this a necessary consequence of the use of lime, and ought it therefore to be forbidden or discontinued?

SECTION II.—HOW LIME EXHAUSTS THE LAND.

Lime acts in several ways so as ultimately to lead to this result. Thus—

1°. As the organic matter decays more rapidly, the mineral substances which exist in it are also liberated in larger proportion than if the land had not been limed, and are thus brought into a condition in which they can be more abundantly removed from the soil by the agency of natural causes.

2°. The same is true of the soluble substances contained in the mineral and rocky fragments which are mixed with the soil. Whatever amount of action lime may exercise in liberating potash, soda, magnesia, silica, sulphuric acid, or phosphoric acid from these frag-

ments, it will to that extent make these substances more easily and quickly removable from the soil.

But as the absolute quantity of potash, soda, &c., in all our soils is really enormous, though the proportion compared with their other constituents is small, it does not at first appear how the mere removal of a certain part of these substances should have a very serious effect upon the general fertility of any piece of land. Still it is not difficult to comprehend one way, in which by the action of lime, the liberation of potash and other valuable matters from this source may by the action of lime be for a time rendered large, and may afterwards, for another period, be very greatly diminished.

All the mineral fragments are of an appreciable size. The lime acts upon the exterior of these fragments, and liberates, we shall suppose, the alcaline matter. But the surface of the fragment does not on that account necessarily crumble down and expose a fresh face to the action of the lime. On the contrary, the old surface may adhere, surrounding the fragment with a coating through which the lime cannot act, and may thus prevent the further liberation of alcaline or other soluble substances, though these may still be abundant in the interior of the mineral mass.

By an action of this kind the surface of all stones—except lime-stones—which lie immediately beneath a layer of peat, come to have the same uniform grey siliceous covering, so that the real nature of the stones can only be discovered by breaking them. The acid matter of the peat dissolves their iron from red sand-stones—the alumina from hard clay-stones—the lime, magnesia, and alcaline matter from fragments of whin-stone—and even upon flint it acts in a similar manner, leaving the same insoluble siliceous coating upon all. It is so with the fragments of rock upon which lime acts in the soil—and it is easy, therefore, to understand how any li-

beration of alcaline or other matter from such fragments may at one time be large, and yet may afterwards diminish in a very sensible degree.

3°. Now these various substances, organic and inorganic, being decomposed, and their constituents set free more abundantly and more rapidly, the roots of plants obtain them more readily and in greater abundance, and thus the plants themselves grow more rapidly and to larger size, and perfect all their parts more completely. In other words, larger crops are grown, and by those larger crops much more matter of every kind is carried off the soil.

But besides the nitrogen, carbon and other so-called organic elements which the plant draws from the soil it takes up at least eight or nine mineral substances in greater or less proportion. These are sulphur, phosphorus, chlorine, potash, soda, lime, magnesia, and the oxides of iron and manganese. The larger the crop the greater the quantity of each of these which is carried off—and therefore in so far as lime is the means of causing larger crops to grow, in like proportion must it be the means of causing the land to be more rapidly exhausted, of all these substances. The more rapid exhaustion of limed land therefore is caused mainly by the production and removal of a larger amount of produce in a given time.

Other considerations, however, have also a direct bearing upon this subject. In our climate the rains which fall upon the soil cannot fail to wash soluble matter out of it. When the land is thoroughly drained and subsoiled so that the rain sinks where it falls, and makes its way though nearly three feet of soil before it escapes, it is a question whether in ordinary circumstances, it will carry away much more than it brings with it from the air. The vegetable matter of the soil tends to retain the soluble saline matter and to keep it

from being washed away, and this is another of the useful purposes on account of which its presence in considerable proportion becomes desirable where we wish to maintain a soil in a state of high fertility.

But the lime as we have seen diminishes the proportion of vegetable matter in the soil, and at the same time increases the amount of soluble matter set free. That is to say, it brings more valuable matter into a soluble condition, while it renders the soil less capable of retaining it. The rains, therefore, ought to have more power over highly and frequently limed land in washing out the valuable kinds of food for plants which it contains. They may in fact be one of the natural instruments by which the exhausting of limed land is immediately produced.

SECTION III.—DOES LIME NECESSARILY EXHAUST THE LAND?

To this question the considerations above presented enable us to answer in the negative. We have already laid down as a principle in practical agriculture that, in our climate, the addition of successive doses of lime at certain intervals is necessary to the highest fertility of the land. It is the part of enlightened practice so to treat the land besides, that this addition of lime shall not prove an instrument of final exhaustion. The exhaustion produced by the use of lime has always been observed in places where either successive doses of lime had been laid on as the sole application to the land, or where too scanty supplies of other manure had been given to the fields.

Now, where lime only is given to the land it is most unreasonable to expect its fertility to be maintained. Besides the purely organic matter carried off—the nine

mineral substances mentioned in the preceding section are yearly removed from the soil by the crops, and only one of these, the lime, is returned in the form of an artificial application. Can anything else but exhaustion follow from such practice?

Again, the crops are greatly larger than before, and, therefore, the quantity of all these substances carried off must be much greater than usual. A more speedy exhaustion, therefore, must be expected than if only the ordinary poor crops had been reaped.

Nor do small manurings of other kinds suffice to prevent this exhaustion. If an ordinary manuring be applied while an extraordinary crop or a series of extraordinary crops is carried off the land, exhaustion must follow as certainly, though more slowly, as if nothing but lime had been laid on.

To keep land in good condition we must, as a general rule, add as much of everything as we carry off. Let this be done upon limed land, and no exhaustion need be feared. If the land yield us large crops, we ought as liberally to manure it. We cannot take out of the land constantly and add nothing without impoverishing it; but we can add enough to supply all we carry off, and yet farm our land profitably.

This is now understood by our best practical men, and in Germany is expressed by the rhyme—

> The use of marl without manure
> Will only make the farmer poor.

SECTION IV.—OUGHT THE USE OF LIME EVER TO BE FORBIDDEN, OR OUGHT IT TO BE CONTINUED, RESUMED, AND REGULATED?

The function of lime in the soil and the cause of the exhaustion produced by it being both clearly under-

stood, the proper course to be adopted both by landlord and by tenant in regard to the use of it becomes plain and intelligible also.

1°. *Ought the use of lime ever to be forbidden?*—It would be improper to decide this so absolutely in the negative as to say that a proprietor should have no discretion in any case to forbid a bad tenant from continuing to add lime to the utter exhaustion of his land. It is better, however, to give such a tenant notice to quit, than by enforcing a regulation which is inconsistent with high farming to put it out of the power of a good husbandman to bring his land into the highest state of cultivation.

Seeing how often, during a former generation, uninstructed tenants ruined their land by constant liming, and being themselves ignorant of the way in which lime operated, and unable therefore to see any remedy, except in prohibiting the use of lime altogether, both proprietors and agents have introduced clauses into their agreements by which the farmers over entire estates have been forbidden for the future to add a particle of lime to their land. The ancient illustration of forbidding the use of fire, because of the dangerous burnings it sometimes caused, applies to this as well as to many other cases. It is profitable to apply lime: it is not necessarily exhausting,—why then should it be forbidden?

2°. *Ought the use of lime to be resumed?*—In some districts, in consequence of the total absence of any good effect from further applications, the use of lime has been voluntarily abandoned by practical men. Ought it in such districts to be again brought into use?

As a general rule, it ought. And the reasons are plain to the reader of the preceding pages. Theory says that a certain small proportion of lime is necessary to every plant as part of its natural food, and this it

ought to be able to collect easily and rapidly. Experience says that land otherwise well treated ceases gradually to produce good crops, unless a certain quantity of lime be added to it along with the manures usually applied. No district, therefore, to which lime or marl has in former years been found to be of service, can long be maintained in a high state of fertility, unless calcareous matter in some form be mixed with it from time to time. But in special cases it may not be proper at once to resume the application of lime. So much may have been incorporated with the soil in past years, that it may be unnecessary and therefore inexpedient to recommence the practice of liming or marling for years to come. The past history of the farm, however, or a chemical analysis of the soil can alone determine where such special cases exist.

3°. *Ought the application of lime to be regulated.*—Were our tenantry once adequately instructed neither restrictions as to crops nor regulations as to lime would be required. This proper state of education among the agricultural classes of the country constitutes that utopian condition to which we look forward as the highway to that great and rapid improvement which British agriculture is hereafter destined to attain. But while education is spreading, restrictions and regulations cannot in most cases be avoided.

In regard to lime, therefore, the erroneous idea must be dispelled from the minds of all parties that lime and manure, in the ordinary sense of the term, are identical. Clauses will then disappear from agreements—such as that tenants shall lime *or* manure once within so many years—that for every ton of hay or straw sold off the farm so much manure *or* lime shall be brought back, and so on. Clauses such as these are not only evidences of defective knowledge, but they encourage and hasten on the very evils which protracted and injudicious liming is sure in the end to produce.

In like manner, tenants who lime once and manure once in a seven years' rotation,* will no longer speak of having manured twice in seven years and thus having done well by their land—but the functions of each application being rightly understood, the manuring will be prosecuted more, while the liming may not be attended to less.

The addition of lime to land in ordinary condition should be regulated so that for every ton of lime so many—perhaps ten tons at least—of farm-yard manure should be added. Or in the absence of farm-yard manure an equivalent of some other analogous manure—guano, rape-cake, bones, &c.—should be substituted. The condition of the land of course—its richness or poverty—its condition as to previous liming, &c., must, of course, be taken into consideration in determining the relative proportions in which the lime and manure are to be added. And in districts where yearly holdings exist, all compensation for unexhausted lime should be made contingent upon the application also of the due proportion of enriching manure.

* Such as that followed on a farm I lately visited in Denbigh, where turnips, with a heavy manuring, are followed by wheat, barley, seeds for two years, then wheat, after 7 to 10 tons of lime on the clover stubble, followed by barley, and then again turnips, with farm-yard manure.

CHAPTER IX.

Length of time during which lime acts. Of the sinking of lime into the land. Connection of lime in the subsoil with the economy of deep ploughing. Why liming requires to be repeated. It is washed out by the rains. Influence of the quantity of rain that falls, of the exposure of the land, and of the natural porosity and chemical composition of the soil. Natural sources of liming in some localities. Influence of the nature and inclination of the underlying rocks on the necessity for repeated additions of lime.

SECTION I.—LENGTH OF TIME DURING WHICH LIME ACTS.

It is the fate of nearly all the superficial improvements of the soil, that they are only temporary in their duration. The action of lime ceases after a time, and the land returns to its original condition. The length of time which must elapse before this takes place will depend, among other circumstances, upon the quantity of lime added to, or originally contained in, the soil—upon the kind of cropping to which it is subjected—on the nature of the soil itself—on the slope, exposure, and natural moisture of the land, and on the climate in which it is situated.

We have seen that on the arable lands of the south of Scotland 20 years is the longest period during which the doses there applied act beneficially upon the crops—while in other parts of the country renewed applications are considered necessary at much shorter intervals. Mr. Dawson, of Frogden, who introduced the practice of liming into the Border counties of Scotland, observed that, when applied for the first time, and harrowed in with the grass seeds, its effecting improving the sub-

sequent pasture was sensible for 30 years after. A heavy marling or chalking in the Southern or Midland counties of England is said also to last for 30 years,* and the same period is assigned to the *sensible* effect of the ordinary doses of lime-sand in Ireland, and of shell-sands and marls in several parts of France.

The effect of the lime lessens gradually, and though at the end of an assignable number of years it becomes almost insensible, yet it does not altogether cease till a comparatively distant period. This period indeed is in in some cases so protracted that intelligent practical men are in many districts to be met with who believe —that certain grass lands would *never* forget a good dose of lime (p. 109, note).

SECTION II.—OF THE SINKING OF LIME INTO THE SOIL.

One of the causes of this gradual diminution of the action of lime is to be found in the singular property it possesses of slowly sinking into the land, until it almost entirely disappears from the surface soil. It has been long familiar to practical men, that when grass lands, which have been limed on the sward, are after a time broken up, a white layer or band of lime is seen beneath the surface at a greater or less depth, in proportion to the time which has elasped since the lime was applied. Upon arable land the action of the plough counteracts this tendency in some measure, bringing up the lime again from beneath, and keeping it mixed with the surface mould. Yet, through ploughed land it sinks at length, especially where the ploughing is shallow, and even the industry of the gardener can scarcely prevent it from descending beyond the reach of his spade.

* Applied at a cost of 30s. to 50s. per acre, according to the locality.—Mr. Pusey, *Royal Agricultural Journal*, iii., p. 185.

One cause of this sinking may be found in the extreme minuteness of the particles into which slaked lime naturally falls. If a portion of slaked lime be mixed with water it forms a milky mixture, in which some lime is dissolved, but much more is held in suspension in an extremely divided state. When this milk is allowed to stand undisturbed, the fine particles subside very slowly, and are easily again disturbed, but if thrown upon a filter they are arrested immediately, and the lime-water passes through clear. Suppose these fine particles to be mixed with the soil, and the rain to fall upon them, it will carry them downwards through the pores of the soil till the close subsoil acts the part of a filter, and arrests them. This tendency to be washed down is common not only to lime but to *all minutely divided earthy matter of a sufficiently incoherent nature.* Hence the formation of that more or less impervious layer of finely divided matter which so often forms the subsoil beneath free and open surface soils. And that lime should appear more particularly to sink on any cultivated field, may arise partly from its whiteness, which makes it more visible, and partly from the circumstance that the continued action of the rains had long before carried downwards the finer incoherent particles of other kinds which existed naturally in the soil, and therefore could find little else but the lime on which this action could be exercised.

This explanation is satisfactory enough in the case of light and open soils, which are full of pores, but it appears less so in regard to stiff clays and to loamy soils which are not only close and apparently void of pores, but seem themselves to consist of particles in a sufficiently minute state of division to admit of their being carried down by the rains in an equal degree with lime itself. This difficulty induced Lord Dundonald to suspect the agency of some chemical principle in producing

the above effect. "In clayey and loamy soils," he says, "which are (?) equally diffusible with lime, and nearly of the same specific gravity, the tendency which lime has to sink cannot be accounted for simply on mechanical principles." (*Agricultural Chemistry*, p. 45).

It is the experience of the practical man that all the substances he lays on his fields sink more or less rapidly. The clay applied in gaulting the fenny districts sinks, and the more rapidly the finer it is permitted to be mellowed by the action of winter before it is mixed with the surface soil. Sand, marl, and lime-sand also sink, and the heavier parts especially of town dung sink, and years after they have been spread over the fields may be brought up again by a deeper ploughing. All these forms of sinking must be in great part mechanical.

There does, however, appear to be this much peculiar in the sinking of lime, that it proceeds with a kind of regularity, and forms layers or thin perceptible beds, which have long attracted the especial notice of the practical man. It is not unlikely, therefore, that the sagacity of Lord Dundonald may point to a true reason, when he supposes it to be connected with the operation of some chemical cause.

Though unwilling to offer to the practical reader mere hypothetical causes in regard to a point which it must be very difficult to clear up by actual observation, yet there are two possible ways in which this peculiar mode of apparent sinking in the case of lime may be accounted for—

1°. When quick lime is spread over the land, the rain that falls dissolves a portion of it and carries it downwards. But it is believed that wherever air penetrates into the soil, carbonic acid is continually produced by the decay of the vegetable matter it contains, —and that this carbonic acid lingers especially in the

lower parts of the soil where the air is least frequently changed. As the lime-water descends, therefore, it comes into an atmosphere of carbonic acid, and the lime it contains is changed into carbonate (or chalk), which separates from the water and gradually collects into a layer of greater or less thickness.

2°. Or, suppose all the lime on the surface to be already changed into carbonate, as we have seen that it has a tendency to be by the absorption of carbonic acid from the atmosphere—pure water will not then dissolve it, and the process described above cannot come into operation. But water charged with carbonic acid dissolves it (p. 4), and it is in this way that it is held in solution in our hard spring water. Rain water is always, to a certain extent, charged with this carbonic acid. When it falls upon the soil, therefore, it is capable of dissolving, and in fact is known to dissolve and carry down with it, a portion of lime into the underparts of the soil.

Now the roots of plants are believed to have the power of absorbing carbonic acid when it is presented to them in a state of solution in water, and at the same time of rejecting or refusing to take in certain other things which may at the same time be presented to them by the same water. Thus while in the soluble state here spoken of, plants may and probably do take in lime to form their substance, still they may also extract from the water the excess of carbonic acid by which the lime is held in solution, and cause it to fall or deposit itself in the soil in the form of insoluble carbonate. In this way, at that depth in the soil where the roots are most active, the layer of lime we are attempting to account for may be gradually collected.

It does not, however, appear how these chemical modes of operation can cause the layer of lime to descend deeper, the longer it has been applied to the land—as

if it sank in a body and went down gradually. It may indeed be that the carbonate of lime, in the second mode of action I have described, may deposit itself around the slender roots and gradually destroy them, and that another set of rootlets may form below to arrest the lime in their turn as it descends again from the renewed operation of the same cause.

I am unwilling, however, to insist upon these chemical actions as real causes of the appearance in question. I state them as possible causes; the reader will judge how far he thinks them probable.

I would, however, as a probable cause of this sinking in the case of old grass and pasture lands, as well as of the sinking of other applications—advert to the action of earth-worms, which are so abundant in many localities. There is every reason to believe that in numerous places the improvement of grass land, when laid down to permanent pasture, is very much to be ascribed to the constant agency of these minute creatures. Not only do they, by their borings, keep the soil constantly open and porous, but by the fine matter they spew out and leave on the surface, they enrich it with a succession of most valuable top-dressings. On a close shaven lawn the quantity thus brought to the surface in a single night often appears surprising, and that which to many appears unsightly to the eye, is a means of permanently improving the green sward itself. So great, at last, is the quantity of fine matter thus laid on the upper soil that some have not hesitated to ascribe the entire production of many of our richest surface soils to the agency of the earth-worm.*

It is probable, therefore, that by bringing up other earthy matters only, and throwing them out on the sur-

* See my *Lectures on Agricultural Chemistry and Geology*, Second Edition, p. 752.

face of the limed land, these insects may be the means also of causing the lime apparently to descend. And this supposed agency is quite in agreement with the observation that the longer the lime has been applied, the deeper it is found to have gone down into the soil.

SECTION III.—CONNECTION OF LIME IN THE SUBSOIL WITH THE ECONOMY OF DEEP PLOUGHING.

I may here briefly advert to the connection which exists between the presence of this lime in the subsoil and the practice of deep ploughing, which in some districts may with safety be followed, while in others it is sure to be attended in the first instance with injurious effects.

Over large breadths of our island an unproductive layer of yellow or red clay, or of some other more or less hard and impervious matter is met with immediately below the cultivated surface. To bring up this lower soil with the plough is in many cases attended by a diminution in the produce of the field. It is this circumstance which preserves the high old-fashioned ridges which are still seen, especially on our clay soils. When the top of the ridge is pared off and put into the hollow furrow, the unproductive subsoil is laid bare, and many years often elapse before the *crown* of the old ridges is restored again to an average state of productiveness.

As a general rule it is unsafe in this way to lay bare the tops of ridges, or to plough deep into previously undisturbed land. It is safer, as a general prescription, that the land should be thorough drained, and subsoil ploughed a year or two before any attempt is made to deepen the surface or active soil, as it is called by some, by bringing up the under-soil with the plough. Yet there

are certain cases in which this deep ploughing may be at once adopted without much risk of injury to the land. Thus—

1°. When the soil is of alluvial origin—a deposit formed along the banks or at the estuary of a river—it is generally of a uniform quality for a very considerable depth. Hence when the few upper inches have become more or less exhausted, a deeper ploughing will bring up a healthy virgin soil, which will yield as rich returns of corn as the original surface had done.

2°. Many subsoils possess a poisonous ochrey character, into which the roots of plants refuse to enter. These it is often dangerous to bring to the surface, though some even of them admit of being at once broken up by a deeper ploughing.

Some of these ochres and pans contain much vegetable matter—as much as 20 to 40 per cent. of their whole weight in the dry state. Where this is the case, I have known them at once broken through and cast up in lumps upon the surface without injury to the succeeding crops of corn. The air and frost gradually crumble and mellow them, and the presence of so much vegetable matter prevents the iron they contain from proving hurtful to vegetation.

3°. But what more especially concerns our present subject, is the fact, that *wherever lime abounds in the subsoil* it may be brought up at once not only with impunity but often with manifest benefit to the upper soil. The presence of lime in a soil in any notable proportion is generally indicated by a more or less sensible effervescence—or escape of bubbles of gas—when strong vinegar or diluted muriatic acid is poured upon it. Wherever this is the case with a subsoil it partakes more or less of the character of a marl, and may with confidence be brought up to the surface by a deeper-going plough.

But the natural sinking of lime, of which I have spoken in the preceding section has a tendency to accumulate it in the subsoil—and hence on fields that have been long and frequently limed—not only may a deeper ploughing be in most cases adopted with safety. but by this improved practice the farmer may bring up and render a second time available, stores of lime which had previously sunk beyond the ordinary reach of his implements, and been rendered in a great measure useless to vegetation.

SECTION IV.—WHY LIMING REQUIRES TO BE REPEATED.

Lime which sinks in the manner described above does not wholly escape, but may, as I have said, by judicious management, be again brought to the surface. The ploughing of a deeper furrow may turn it over, and again place it in contact with the air. The sowing of deep-rooted and lime-loving crops such as lucerne and sainfoin which thrive in such soils, is also useful. They draw up into their stems and thus restore to the surface a portion of the lime which had previously descended, and in this way make it available to the after-crops. These and similar methods recover more or less completely to the farmer the lime which would otherwise be lost.

Such a sinking, therefore, does not necessarily call for the addition of a fresh dose of lime, nor does it explain why in practice the application of lime to the land must at certain intervals be everywhere repeated.

Experience everywhere teaches that the influence of the lime we have laid upon our fields after a time gradually diminishes. The grass becomes sensibly less rich and fuller of weeds every year, the crops of corn less abundant, the sample of grain inferior, and the kind

of grain which the land will ripen less valuable. Does the lime actually disappear from the soil, or does it merely cease to act? This question was most distinctly answered by an experiment of Lampadius. He mingled lime with the soil of a piece of ground till it was in the proportion of about $1\frac{1}{5}$ per cent. (1·19 per cent.) of its whole weight, and he determined subsequently by analysis the proportion of lime it contained in each of the three succeeding years.

	Carbonate of Lime.
The first year it contained	1·19 per cent.
The second year	0·89 ...
The third year	0·52 ...
The fourth year	0·24 ...*

There can be no question, therefore, that the lime gradually disappears or is removed from the soil.

The agencies by which this removal is effected are of several kinds.

1°. In some cases it sinks, as we have already seen, and escapes into the subsoil beyond the reach of the plough or of the roots of our cultivated crops.

2°. A considerable quantity of lime is annually removed from the soil by the crops which are reaped from it. We have already seen (p. 125) that in a four years' rotation of alternate green and corn crops the quantity of lime contained in the average produce of good land amounts to about 200 lbs. This is equal to 50 lbs. of quick-lime or 90 lbs. of carbonate of lime *every year*. The whole of this, however, is not usually lost to the land. Part at least is restored to it in the manure into which a large proportion of the produce is usually converted. Yet a considerable quantity is always lost—escaping chiefly in the liquid manure and in the drainings of the dung-heaps—and this loss must be repaired by the renewed addition of lime to the land.

* Schübler, *Agricultur Chemie*, ii. p. 141.

3°. But the rains and natural springs of water percolating through the soil remove, in general, a still greater proportion. While in the quick or caustic state, lime is soluble in pure water. Seven hundred and fifty pounds of water will dissolve about one pound of lime. The rains that fall, therefore, cannot fail, as they flow over or sink through the soil, to dissolve and carry away a portion of the lime so long as it remains in the caustic state.

Again, quick-lime, when mixed with the soil, speedily attracts carbonic acid, and becomes, after a time, converted into carbonate, which is nearly insoluble in *pure* water. But this carbonate, as we have already seen (p. 4), is soluble in water impregnated with carbonic acid—and as the drops of rain in falling absorb this acid from the air, they become capable of dissolving an appreciable quantity of the finely divided carbonate when they meet with it in the soil. Hence the water that flows from the drains in our cultivated fields is almost always impregnated with lime, and sometimes to so great a degree as to form calcareous deposits in the interior of the drains themselves, where the fall is so gentle as to allow the water to linger a sufficient length of time before it escapes into the nearest ditch or brook.

It is impossible to estimate the quantity of lime which this dissolving action of the rains must gradually remove. It will vary with the amount of rain which falls in each locality, and with the slope or inclination of the land; but the cause is at once universal and constantly operating, and would alone, therefore, render necessary, after the lapse of years, the application of new doses of lime both to our pastures and to our arable fields.

To illustrate the varying amount of this kind of action in different localities, I insert the following tabular view of the yearly quantities of rain that fall in different parts of our island, in inches :—

London	23 inches.	Manchester ...	36 inches.
Edinburgh...	24 "	Lancaster......	40 "
Epping	27 "	Penzance	45 "
Bristol	29 "	Kendal	54 "
Liverpool	34 "	Keswick	67½ "

From this table it is apparent that if the rain really exercise a dissolving action, such as I have described, it must do so around Kendal and Keswick to an extent nearly three times greater than it does about London or Edinburgh. At Penzance and Lancaster again, the effect of the rains in exhausting the land of lime must be nearly double what it is around the capitals of England and Scotland.

An obvious practical deduction from this fact is that the system of liming adopted as the best in one district may not be at all suited to the climate of another. Where much rain falls the land may not only bear without injury, but may require in order to ensure its full productiveness, a more liberal and more frequent application of lime. We ought, therefore, to study well the local circumstances as well as the farming skill of a district before we pronounce that the system of liming followed in it is bad, or that what we, from experience in other places, consider a better practice should be adopted in its stead.

This effect of the rain in washing or dissolving out the lime of the soil is so marked, that it is no uncommon thing to find soils which rest immediately upon limestone or even upon soft chalk rock almost entirely destitute of lime. From a soil about 12 inches deep resting immediately upon and apparently formed from a crumbling magnesian rock in the County of Durham, I collected two portions, one at the depth of two and the other of six inches below the surface, and caused the proportions of lime and magnesia in them to be determined. These were found to be as follows :—

	Taken at 2 inches.	Taken at 6 inches.
Carbonate of lime......	5·22 per cent.	1·91 per cent.
Carbonate of magnesia	2·00 per cent.	1·35 per cent.

Instead of increasing as it approached the rock the proportions of lime and magnesia diminished. The field was near a quarry and lime-kiln and had been frequently limed : to this was owing the larger per-centage near the surface.

In chalk soils this comparative absence of lime from the upper soil has been frequently observed, and it serves to explain, what at first sight appears surprising, that the chalking of such land should be so prevailing a practice, and that it should be attended with such generally beneficial effects.

I shall here add only one other remark upon this subject. In tropical countries the mean quantity of rain that falls is much greater than in our temperate climates. As a general rule it increases constantly, as we proceed from the poles to the equator. It would appear, therefore, that the necessity of frequent liming should increase also as we advance in the same direction.

4°. During the decay of vegetable matter, and the decomposition of mineral compounds, which take place in the soil where lime is present, new combinations are formed in variable quantities. Some of these are more soluble than the carbonate of lime itself, and therefore hasten and facilitate this washing out of the lime by the action of the rains. Thus chloride of calcium, nitrate of lime, and gypsum are all produced—of which the two former are eminently soluble in water—while organic acids also result from the decay of the organic matter, with some of which the lime forms compounds (salts) which are readily soluble, and therefore easily removed by water.

5°. The ultimate resolution of all vegetable matter into carbonic acid and water, which is its tendency in

the soil, likewise aids the removal of the lime. For if the soil be everywhere impregnated with carbonic acid, the rain and spring waters that flow through it will also become charged with this gas, and thus be enabled to dissolve a larger portion of the carbonate of lime than they could otherwise do. Thus theory indicates, what I believe experience confirms, that a given quantity of lime will disappear soonest from a field, if under arable culture, in which animal and vegetable matter is most abundant.

6°. I may simply notice as additional circumstances which will modify the effect of the rains that fall—first the natural porosity of the soil itself, which will admit of the rain-water passing through and washing it more or less easily—second, its state as to thorough drainage, for if it be already full of stagnant water, the rain cannot penetrate, and therefore cannot wash it, at least below the surface—and lastly, the physical slope or inclination of the land. The effect of heavy rains in washing a sloping surface will obviously be very much greater than upon the flat plain beneath. What descends in this way from the slope may even render unnecessary any artificial addition of lime to the level land at its feet.

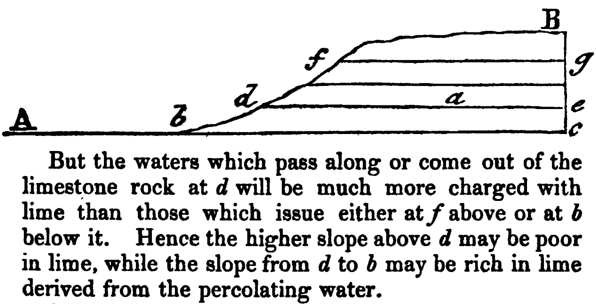
SECTION V.—NATURAL SOURCES OF LIME IN SOME LOCALITIES.

This last observation leads me to advert to a question which has often perplexed the practical man—why in the same district one field or farm may be benefitted by, and yield a profit upon, every addition of lime, while another field or farm, of similar soil and otherwise treated alike, may exhibit no trace of any beneficial action when lime is laid upon it. Such observed differences may

most naturally be ascribed to the existence of some source of lime in the one spot which does not exist in the other.

A very probable source of this kind is to be found in the rising of springs from the rocky beds below the soil, which being charged with lime, impart it to the soils through which they make their way. If these springs issue from limestone rocks, they are sure to be largely charged with calcareous matter, and as they find their way to the surface only here and there, it is easy to understand how any benefit they produce in the way of liming the land should be limited, and local only.

Thus let A B in the subjoined section represent a gently rising country resting upon beds of rock nearly horizontal, of which beds *a* alone consists of limestone. The water which makes its way between or among these rocks in the higher country will find a natural outlet in springs towards the plain at the points *b, d, f,* &c., where the partings of the rocks come to day.



But the waters which pass along or come out of the limestone rock at *d* will be much more charged with lime than those which issue either at *f* above or at *b* below it. Hence the higher slope above *d* may be poor in lime, while the slope from *d* to *b* may be rich in lime derived from the percolating water.

Suppose now a brook to run along the base of the slope at *b*, and thus to cut off the hill waters from the plain A *b*, the whole surface from A to *b* may be naturally poor in lime, and may abundantly repay the expense of applying it, while the zone *b d* is rich in

lime, and shows no improvement when lime is added to it.

And if again along the hill-side the discharge of calcareous water takes place in particular spots only, fields may occur alongside of each other which, though apparently of similar soil, and formed in the same way, exhibit similar differences as regards the fertilizing action of lime when applied to them artificially.

The above illustration shows how a familiarity with the geological structure as well as with the climate of a country, are necessary to explain the anomalous appearances which now and then present themselves in the practical improvement of an agricultural district.

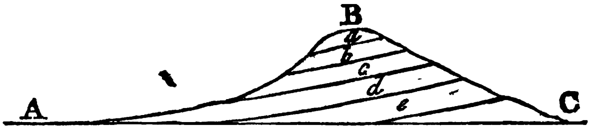
SECTION VI.—INFLUENCE WHICH THE MODE OF INCLINATION OF THE UNDERLYING ROCKS MAY EXERCISE ON THE NECESSITY FOR REPEATED ADDITIONS OF LIME.

Of this use of geological knowledge I may present another illustration.

It has been observed that not only in adjoining pieces of land is the profit of adding lime very different on some occasions, but that on opposite sides of a hill between which no apparent difference exists as to the quality of the soil, the use of lime is attended at times with very unlike effects. The late Mr. Oliver, of Lochend farm, near Edinburgh—a person well-known and much regretted among Scottish farmers—first drew my attention to this curious fact as observable in a locality with which he was well acquainted, and asked me to explain the cause.

I offer the following explanation of the way in which such circumstances *may* arise, though I have not had

an opportunity by personal observation of determining how far it is strictly applicable to the locality mentioned to me by Mr. Oliver.



Let A B C be a cross section of a hill or ridge on which the beds of rock, *a, b, c, d,* are considerably inclined and slope towards A, and let one of these, the bed *b,* be a limestone. Whatever water makes its way into this hill will naturally flow along the inclined partings of the beds and will issue in springs at various points on the slope from B to A. The water issuing from or passing through the limestone bed *b* will follow a similar course and will impart calcareous matter to the soil on the same slope. But on the slope B C no springs will break forth. Any rain also that falls will tend to wash the soil and sinking in between the rocks will make its way among them towards the slope B A. Hence, if long cultivated without the addition of lime the slope B A may continue productive, while from B to C the soil may have become comparatively unfruitful—because of the gifts bestowed by the water upon the one and the robbery committed by it upon the other.

The addition of lime, for the same reason, may greatly improve the one slope B C, while it produces no remunerative effect on the other slope B A. The lime supplies what the one is in want of and is thankful for, it gives to the other a constituent of which it already contains enough.

CHAPTER X.

Effects of lime on vegetable and animal life. Caustic lime destroys the seeds of weeds, prevents smut, and extirpates moss. Its use in preparing seed for sowing. Its action on seed potatoes, and its alleged use in preserving them. It kills slugs and wire-worms, renders paring and burning unnecessary, makes deeper ploughing practicable, and prevents the ravages of the fly in turnips. Action of chalk and quick-lime on the affection in turnips called fingers and toes. Nature, cause, and cure of this disease. How lime prevents foot-rot in sheep.

Besides its use as a food of plants, and its chemical action upon the soil itself—both upon the mineral substances and upon the animal and vegetable matters it contains—lime is valuable to the farmer in consequence of the effects it produces upon vegetable and animal life. I shall briefly consider the most important of these.

SECTION I.—ACTION OF LIME ON THE SEEDS OF WEEDS, ON THE MOSSES, AND ON FUNGI.

1°. *Lime kills the seeds of weeds.*—We have seen that dry slaked lime exercises comparatively little action upon dead vegetable matter when sufficiently free from moisture. The same is true in regard to the vitality of seeds. Dry slaked lime, if it injure them at all—acts upon them very slowly. Much, of course, will depend upon their nature. Such as are covered with a thick husk, like barley and the oat, will resist its influence longer than those which, like wheat, are nearly naked. Such also, as like linseed and the turnip and rape seeds, are rich in oil, will be differently affected from those in

which, as in the seeds of our corn plants, the proportion of oil is comparatively small.

It is one of the benefits expected by the farmer from making and applying lime composts that the seeds of the weeds he mingles with them shall be killed and thus rendered useful instead of injurious to his land. In this respect he is occasionally disappointed, finding the application of composts to increase the foulness of his land. This result of course ought to be carefully guarded against. The proportion of lime must be sufficiently great, it must be brought into contact with all the seeds, and air and moisture must be admitted in sufficient quantity to allow of those chemical changes, necessary to the destruction of the seeds, which cannot proceed without their presence. These latter ends are attained by occasionally turning the compost when the weather is moist.

Where composts are made with unslaked lime, the vegetable matter, whether living or dead, is destroyed or charred by the simple abstraction of water. The lime slakes itself at the expense of the substances with which it is mixed, it heats so much as sometimes to set fire to the combustible matters contained in the heap, and always more or less decomposes them by the high temperature which it produces. But after it is fully slaked, the whole heap is remarkably dry in the interior, and unless it be turned over so as to admit air and moisture to a certain extent, any seeds which have escaped its action while slaking, may continue uninjured for an indefinite period.

The best composts with ditch scourings, couch roots, and other weeds, is made by mixing them with lime newly slaked, containing from 2 to 5 cwts. of salt to each ton of lime (p. 49).

2°. *Lime extirpates moss.*—It is usually a want of drainage in the land or an excessive moisture in the air

which covers our grass fields with moss. Whether any other causes, such as the quality of the soil, tend to the same effect it is unnecessary here to enquire. It appears certain that even on undrained land the application of lime has the effect of extirpating this moss. For this purpose it may be applied either in one large dose spread over the field—the effects of which will be visible for many years—or in small doses frequently repeated. On lawns a harrowing early in spring, to tear up the roots a little, followed by the application of a few bushels of slaked lime sown with the hand and afterwards by a bush-harrowing or rolling—if repeated year by year, or alternately with a couple of bushels of bones dissolved in sulphuric acid—would keep the grass free from moss and bring up an early, green and healthy herbage.

3°. *Lime kills the seeds of fungi.*—The smut in wheat, oats, barley, &c., is in each case caused by a species of fungus, the seeds of which usually adhere to those of the grain itself when it is committed to the ground. They are excessively minute and generally cling to the exterior of the grain, and attach themselves with great ease to such as are covered with a husk.

To prove this latter fact I caused some seeds of Scotch oats to be deprived of their husks and to be sown in pots, while another portion of the same seed with the husks attached was sown in other pots near them. Both came up and grew well—but several of the plants from the seeds in their natural state were smutted, while all those from the naked seeds were free from the fungus. This experiment was made in 1846—the prevalence of smut in the oats of Scotland having attracted much attention in the two previous years.

It is customary to steep and prepare seeds in various ways—especially seed wheat—for the purpose of pre-

venting the attacks of fungi in the growing plant. Whether urine, or salt, or copperas, or arsenic be employed for this purpose, slaked lime is almost universally mixed with the wet seed as the final step in the process. This lime serves to dry the seed, but it also performs a chemical function, and assists besides in the destruction of the seeds of the fungi and the eggs of insects which may be attached to the grain. When the seed has been steeped only in a solution of salt, it is not unlikely that the most important part of the action may depend upon the lime. A steep of lime water, followed by a dusting with dry lime would probably without other aid prevent the attacks of smut both in our wheat and in our oat crops.

SECTION II.—ACTION OF LIME ON SEED POTATOES AND ITS USE IN PRESERVING THEM.

It is a common practice in many districts to dust the cuttings of seed potatoes with slaked lime—others prefer burned gypsum. This dusting not only dries the cut surface and prevents bleeding, but serves a further purpose in promoting the growth of the plant. Since the potatoe disease has visited this country the use of lime has been especially recommended, as likely to promote the healthy growth of seed in which the germs of the disease may be supposed to exist.

Mr. Dobson has published the following comparative results of a trial with the same potatoe seed, limed and unlimed :—

" As soon as a few sets were cut, say two or three pecks, they were spread upon a floor, when a quantity of newly-slaked hot lime was sifted upon them through a fine wire sieve, and then well stirred together. This caused the potatoes to emit plentifully their starchy

moisture, which, coming in contact with the lime, formed a perfect shell or crust. If the lime be too long in being applied after the potatoes are cut, they will then only be daubed with lime, the shell or crust not being so hard and perfect.

"The potatoes experimented upon were the Highland early, being all manured alike, all of the same seed, all planted on the same afternoon, and the result was as follows :—

"1°. *The limed*—when they first began to send out fibres, they were strong and of a red colour. They came above ground with a large dark green leaf, the tops got long and strong, covering the ground, and bloomed and appled well. When taken up some time after being ripe, a good crop was the result.

"2°. *The unlimed*—when they first began to send out fibres, they were weak and of a white colour. They came above ground with a small green leaf, were weak and small, and bloomed very indifferently, with scarcely any apples. When taken up early ripe, they were not more than half a crop.

"The great difference in the different stages of progress, as also in the crops at full maturity, was, I believe, caused by applying the lime as above. I would recommend the lime to be applied as hot and as soon as possible after the potatoes are cut, stirring them well together."

The use of lime for preserving potatoes in the pit, or when otherwise stored away, has also been recommended. A sprinkling of lime has been found, both in this country and in America, to preserve potatoes from rotting, which, without such a preparation, heated, fermented, and were in a short time wholly destroyed.

SECTION III.—USE OF LIME IN DESTROYING SLUGS, WIRE-WORM, TURNIP FLY, ETC., IN RENDERING UNNECESSARY PARING AND BURNING, AND IN ADMITTING OF DEEPER PLOUGHING.

1°. *Slugs.*—Where fields are overrun with slugs, a dusting with quick-lime in the early morning before the dew has risen, is said rapidly to kill them. It strengthens the young crop also, and thus hastens its recovery from the injury it has already sustained.

2°. *Wire-worm.*—The wire-worm is generally deeper seated, and for its destruction a larger application of lime is necessary. It should be laid on the stubble in the autumn, after the first ploughing. When applied in spring its success is less certain.

3°. *Turnip fly.*—When the fly begins to attack the young turnip, it is recommended to strew quick-lime along the drills and among the green leaves. The best time for the experiment is in the morning early.*

4°. *The grub. Paring and burning.*—The grub is an enemy which not unfrequently occasions to the farmer the loss of entire crops of corn. Oats, after old poor pasture, and less frequently after clover, are very subject to this form of attack.

* Some practical men doubt the possibility of extirpating the turnip fly where it is once established. As a safeguard against its ravages, they recommended—*First*, to manure liberally, that the plant may rapidly push forward into the second leaf, when the fly ceases to attack it. *Second*, to sow abundance of seed, that the fly may destroy many if present, and yet leave enough for a crop. *Third*, to sow also a couple of pounds of seed broad-cast, that the weaker plants between the drills being preferred by the fly, those intended for the crop will in a greater measure escape. *Fourth*, that all weeds of a similar natural order (Cruciferæ), such as the common charlock (Sinapis arvensis) and the jointed charlock (Raphanus rhaphanistrnm), should be carefully extirpated, as upon these, as well as upon the turnip, this fly feeds, and they are supposed to keep it alive during the intervals of the turnip crops. *Fifth*, to sift these seeds clean from the grain, and afterwards thoroughly to ferment or otherwise destroy them.

One of the purposes served by the ancient, unnecessary, and now nearly exploded practice of paring and burning was the destruction of this worm or grub, which without the burning was sure to eat up the young corn. When the paring is performed and the sods are left for a while on the ground, myriads of grubs may, in many localities be seen by merely turning up the loose sods. The burning destroys all these, and in addition to the immediate benefit of the ashes, preserves the crop from their attacks. With such an enemy to encounter and to destroy, we need not wonder that the practice of paring and burning should in many poor districts have been long and extensively carried on. But the evil is in the soil itself before the ploughing takes place. The insects or their eggs are there. A heavy liming on the sward, a year or two before breaking up, not only improves the grass, mellows and enriches the soil, but destroys the insects it contains. Thus when ploughed up, the burning is unnecessary, the corn is in no danger from the grub, and the rich manuring of the green sod is preserved to the land.

5°. *Deeper ploughing* is also for a similar reason rendered possible in some districts by a heavy liming. Different species of insects, with different habits, colours, and forms, are included by the farmer under the common name of the grub. Some appear, as in the case above described, when the land is ploughed shallow, others show themselves and attack the corn only when the land is ploughed deeper than usual. In several English counties I have met with this objection to deep ploughing, in the mouths of practical men. By going deeper, the insects or their eggs are brought into circumstances favourable to their growth or propagation, and consequently to their injurious attacks upon the corn when sown. If left undisturbed the crop is in a great measure safe.

There is no doubt whatever that in most cases where the land is dry, a deeper ploughing should render the

land more productive,—but it is equally certain that the objection just stated is so far a good one against the introduction of the practice. But can the good not be obtained and at the same time the evil avoided? Is it not possible to kill the insects before or after the deeper ploughing, and thus to avail ourselves of the benefits which both theory and experience indicate as the general results of deepening the available soil?

This I believe to be possible, and in many cases I think it will be effected by a heavy liming laid on in the autumn, immediately after the land has been ploughed to the depth required. If ploughed in spring, of course the lime must be applied at that time, though it will not have so long a time or perhaps so favourable a one for acting injuriously upon the insects brought within its reach.

I add one remark, in reference to all the uses of lime adverted to in this section—that lime slaked with water containing from 2 to 5 cwt. of salt to each ton of lime, will be likely more effectually to destroy insects of all sorts, and under all circumstances, than pure slaked lime applied alone.

SECTION IV.—ACTION OF CHALK AND QUICK-LIME ON THE AFFECTION IN TURNIPS CALLED FINGERS AND TOES.

I take up this subject in a separate section because of its importance—though it is very closely connected with the uses and action of lime, which have been adverted to in the preceding section.

The disease called fingers and toes, though unknown in many parts of England where the turnip culture has as yet attained little extension, has been long familiar to the farmer in other districts, and has been the cause of much disappointment, uneasiness, and loss.

1°. *Appearance of the disease.*—Turnips affected with this *disease*—as it is usually called—in its simplest form, instead of a single main top root, present several roots of this kind, often of equal size, springing from several parts of the bulb, and resembling the fingers of a man's hand. Sometimes these roots are so separate and distinct that the bulb appears to be cleft from beneath into several parts.

At the next stage the turnips or the roots become warty, and large excrescences or swellings grow upon the roots at various parts of their length. These are round or oblong like the toes of the foot, smooth or warty on the surface, and when cut open are more or less spongy, hollow, and discoloured within.

In the third stage the same sponginess and discoloration makes its way into the interior of the bulb, and insects of various kinds are found to have penetrated into its substance. In the last stage the turnip bulb becomes penetrated by what may be called gangrene and ulcers. The interior rots, when cut into emits a disagreeable putrid odour, and the whole becomes unfit for the use of cattle.

In the same field all these stages of the disease may occasionally be seen, and almost every turnip may be affected by it. It often happens, however, that a few turnips only are attacked by the disease, and that in these the fingers and toes only are seen—the interior of the turnips being sound and free from ulcers or putrid decomposition. It is only after the disease has appeared in the same field for several rotations that it is seen in its most malignant form.

2°. *Cause of the disease.*—The cause of this destructive affection of the turnip is by no means certainly ascertained. Is it produced by the attacks of an insect upon the healthy bulb—or is it a natural consequence of some unhealthy condition of the plant itself, arising from some chemical defect in the composition of the

soil? When my attention was first drawn to this subject, I was inclined to the latter opinion; further enquiry, however, has satisfied me that the former is the more probable cause. There are several known facts which throw light upon this enquiry. Thus—

a. If the disease appear in one corner of a turnip field only, in one rotation, it will show itself over perhaps the whole field during the next rotation.

b. It spreads from field to field and from farm to farm, so as if unchecked to extend itself at times over whole districts.

c. When household and farm yard manure of different kinds are applied to the different parts of the same field of turnips, the disease will show itself more malignantly on one of those parts than on the others.

d. If potatoes be planted instead of turnips on one-half of a field in which the disease has previously shown itself, and turnips on the other, then when the growing of turnips on the same field comes round again they will generally be sound where the potatoes were planted, but perhaps worse affected than before on the part which bore turnips during the previous rotation.

All these facts are consistent with the opinion that the turnip is liable to be attacked by a peculiar insect which propagates itself, multiplies and extends its ravages from small beginnings till it is found to be diffused over very considerable areas. This insect does not feed upon the potatoe, and therefore dies, and may disappear altogether where the plant on which it lives ceases to be grown on the same field for a sufficient length of time.* The effect of different manures is probably owing to some of them encouraging or destroying the insect.

* I have heard of cases in which the disease has appeared in the first turnip crop after old grass. Can the supposed insect be brought into a field by the manure or the seed applied to it?

These reasons are scarcely sufficient to satisfy the cautious enquirer that the origin of the evil really and certainly lies in the attacks of such an insect. Nor does it make the evidence much more certain to state that insects are almost invariably found in turnips upon which the disease has made much impression, as the insects thus found may have been attracted by the vegetable matter already in a state of decay. In speaking of the remedy or cure for the disease, however, I shall state other facts which appear more in favour of this than of any other view.

3°. *Cure or remedy for the disease.*—Wherever the turnip has been long cultivated the disease has a tendency to appear. Now in most places in which the disease has been commonly observed and experimented upon it has been found

a. That *chalking*, where that practice prevails (p. 27), removes or prevents the disease.

b. That a heavy liming, at the proper season, prevents its appearance in the succeeding turnip crop.

c. I may add, as a third observation, that all the soils examined in my laboratory, which have been subject to or the scene of this disease, have invariably been found to be very poor in lime.*

* Of this result of analysis I give an example in the case of soils taken from two fields of a farm near Dundee Law belonging to and at present farmed by Sir John Ogilvie. Six samples of soil were taken at depths of three and twelve inches from various parts of the two fields and the proportion of lime soluble in muriatic acid carefully determined in each. The results were as follows:—

	Per centage of carbonate of lime in each of the six samples of dry soil.					
Field now under turnips very much diseased......	0·29	0·33	0·41	0·50	0·53	0·31
Field intended for turnips next season	0·36	0·48	1·11	0·88	1·39	1·26

In all these samples the proportion of lime is very small, much smaller, I believe, than is consistent with the attainment of high

These facts, though they are important as indicating a remedy, are quite as much in favour of the opinion that the disease arises from a deficiency of lime in the soil as that it is caused solely by the attacks of an insect. They had indeed much influence in this direction upon my mind, when this matter was first brought under my notice. The three following facts, however, turn the balance in favour of the insect theory.

d. Mr. Collier, agent to Lord Panmure, found the disease to be prevented by the use of bones dissolved in sulphuric acid as a manure for his turnip crops upon fields previously affected by it. The acid in this manure may be supposed to have destroyed the minute animals or their eggs.*

fertility, independent altogether of the presence of the insect supposed to cause this disease.

* It is fair to add to this statement, however, that others have not obtained equal success from the use of bones and sulphuric acid. Thus in a series of experiments with different manures upon turnips, made by Mr. Dockar, of Findon farm, and published by the Turriff Agricultural Association, the whole field was affected with this disease, and the extent to which it was observed when the different manures were applied, was nearly as is shown in the following table:—

Manures applied.	Proportion of turnips diseased.
1. Bone-dust, 20 bushels per acre	2 in 27
2. Bone-dust, 12 bushels, with sulphuric acid	2 in 6
3. Guano, 6 cwt. per acre	2 in 22
4. Farm-yard manure	Fully as much as any.
5. No application	2 in 7
6. Farm-yard manure and bone-dust, 6 bushels	2 in 5
7. Farm-yard manure, bone-dust, and sulphuric acid	Smaller and more wasted.
8. Farm-yard manure and guano	2 in 10 of the large & all the small ones.
9. Peat, bone-dust, nitrate of soda, and sulphate of ammonia	Many wasted.
10. Farm-yard manure, bone-dust, sulphate of ammonia, and nitrate of soda	Equally wasted.

These results exhibit no very decided good from any of the applications, at least the bones in sulphuric acid, in Nos. 2 and 7,

e. Mr. Wilson, of Cumledge, in Berwickshire, applied lime previous to his turnip crop upon land which he knew to be subject to the disease. On one part of it the lime was spread soon after the autumn ploughing of the stubble, on another part it was not applied till spring as he was unable to overtake the whole before the winter set in. When the turnips came up and bulbed they grew sound and healthy where the lime had been applied after harvest, while they were diseased as before where the lime had been laid on in spring.

f. Sir John Ogilvie informs me that a neighbour of his near Dundee applied lime to prevent the disease, but the turnips which followed it were as badly diseased as before. He laid it on in the spring, however, and this may have been the cause of the failure.

It is not, therefore, the mere presence of lime in the soil as a chemical ingredient which prevents this disease. It seems of more consequence that it should be applied at the right season. When laid on in autumn, it may be supposed either to have more time to destroy the insects or to find them in a condition in which it can act upon them more immediately and more powerfully than in the spring.

This evidence, however, is cumulative only—no single fact is in itself convincing, and therefore the reader will entertain either the one view or the other as the facts may strike him. It is of more consequence to the practical man to know the cure than the cause, and *this*

show no beneficial action. The guano and the bone-dust alone appear to have diminished the disease, probably because the proportion of lime they conveyed into the land was greater than was contained in any of the other manures. It is deserving of enquiry how far other substances will prevent turnips being thus affected, but lime seems at present to be alone deserving of reliance. It is possible, however, that the excess of sulphuric acid in the bones employed by Mr. Collier might be greater, and thus destroy the cause of the disease. This may account for the difference in the results, while it suggests also new and varied experiments.

cure appears to be the application of a large dose of lime to the stubble land in the autumn after it has been turned up by the plough.

Assuming that the disease is caused by the attack of an insect, it is possible, as I have said, that its condition—or state of growth and development—in the autumn may be such as to cause it to be more easily killed by the lime. Or it may be nearer the surface, and therefore more easily reached when the lime is spread upon the land than it can be in the spring. But it may be also that the greater length of time during which it is in the land may give it more opportunities of attacking the insects, and thus enable it more completely to extirpate them.

If there be any special virtue in the *quick*-lime, as one would naturally suppose there may, it is not unlikely that its action upon insect life may depend upon the quantity of rain that falls immediately after it has been laid upon the land.

Every shower of rain that falls dissolves so much of the quick-lime, and carries it down into the soil. It is reasonable to ascribe to this lime-water a hurtful influence upon insect life. The more abundantly therefore it penetrates into the land the more marked must this part of its action be.

Now in our island the largest quantity of rain falls in the later months of the year. Thus, according to Daniell, the mean monthly average fall of rain at London during the year is represented by the numbers in the following table :—

	Inches.		Inches.
January	1·483	July	2·516
February	0·746	August	1·453
March	1·440	September	2·193
April	1·786	October	2·073
May	1·853	November	2·400
June	1·830	December	2·426
			22·199

In this table we see that during the last four months of the year nearly one-half of the whole rain falls. Suppose, therefore, that lime is laid upon the land in september, it will be much more largely dissolved, and washed into the soil before it is changed into carbonate, than if it is laid on in the months of spring, and hence it will exercise a greater action upon insect life. To this influence of climate I am inclined to ascribe a portion of the better effect which follows the application of lime in autumn, compared with what is observed when the liming is delayed till the spring.

Still I would remind the reader that the good effects of liming in reference to this disease are not necessarily dependant upon its being in a caustic state, as the efficacy of chalking in preventing its recurrence clearly shows. It is applied in much larger quantities in the state of chalk, it is true, to produce the effect, and it is likely that the minute state of division and the solubility of caustic lime may be reasons why in the quick state a much smaller quantity is necessary—yet there seems to be in the lime itself, in whatever state it be, some special virtue in preventing this affection of fingers and toes.

SECTION V.—HOW IT PREVENTS FOOT-ROT IN SHEEP.

On some pastures sheep are very liable to the rot, and especially to the foot-rot, and the application of lime to such pastures has been found in many instances to render them sound and wholesome and safe for sheep. This is a valuable fact to know, though it is not easy to explain precisely how the effect follows from the cause.

It is chiefly on wet land that sheep are liable to these diseases. On such wet land coarse and sour grasses grow, and unwholesome substances are produced in the

soil. Lime changes the grasses, and brings up a more nutritious and wholesome herbage. It removes acid substances from the soil, changes those which are undergoing decay so as to prevent the production of injurious exhalations, and to these generally useful influences the results as respects the health of sheep are most likely to be traced.

We have already seen that the general application of lime in a district, like a general drainage, has a marked effect upon the health of its human inhabitants. It is not surprising, therefore, that special good results should follow from its use in reference to the inferior animals also. Any more precise explanation than this, it would be difficult at present to give.

CHAPTER XI.

Use of lime in the state of sulphate. Composition of sulphate of lime or gypsum, in its burned and unburned state. Use of gypsum as a manure. Crops to which it is most favourable. Its use as a fixer of ammonia. Urate. Theory of the beneficial action of gypsum. Why its action is less in some localities than others. Use of mixtures of gypsum and common salt. Use of lime and salt. Use of silicate of lime—the slag of the iron furnaces.

Lime is extensively used in the form of sulphate of lime or gypsum, of phosphate of lime as it occurs naturally in bones, and of bi-phosphate of lime, as *it* is called, which is prepared by dissolving, reducing or decomposing bones by means of sulphuric acid. It is necessary, therefore, briefly to advert to these three compounds of lime to the mode in which they are applied, and to the purposes for which they are laid upon the land. In the present chapter I shall consider chiefly the use of gypsum.

SECTION I.—COMPOSITION OF GYPSUM IN ITS NATURAL AND ITS CALCINED OR BURNED STATES.

Gypsum, as I have already explained (p. 5), consists of lime in combination with sulphuric acid, commonly called oil of vitriol. A hundred pounds of gypsum, in its natural condition, consists of

Lime	46 lbs.
Sulphuric acid	33 lbs.
Water	21 lbs.
	100 lbs.

In its natural state it is colourless, hard, but easily

cut with a knife, and somewhat brittle. But it is tough, and therefore on the large scale difficult to reduce to fine powder. It is less frequently, at least in this country, employed for agricultural purposes in the natural than in the burned state.

When heated to dull redness in an oven or furnace the gypsum parts with its water, and is then composed in a hundred parts of

	Per cent.
Lime	41½
Sulphuric acid	58½
	100

In this burned state gypsum is easily reduced to a very fine powder. When sifted this fine powder is known by the name of plaster of Paris. It has in this state a great desire to combine again with the water it has lost. Hence, if it be quickly mixed with one-fourth of its weight of water and poured into a mould it will in a short time drink in the whole and become solid. Hence its use for cornices and stucco work. When thus mixed with water and become solid it has again the composition of the natural gypsum, though it is much more brittle and more easily reduced to powder.

Gypsum exists in minute quantity in most soils and waters—in the rocks of certain geological formations, such as the new red sand-stone, and in the springs which issue from them—and in sensible proportion in sea water.

It possesses three properties, which are connected either with its mode of action or with its uses in regard to the growth of plants. These are—

1°. That in the presence of carbonic acid and moisture in the soil or elsewhere, it willingly gives off its sulphuric acid to other substances, such as ammonia, or alumina, or even to the roots or leaves of living plants, and becomes itself changed into carbonate of lime.

2°. In the presence of organic matter it is readily decomposed, being changed into sulphuret of calcium.* If carbonic acid be at the same time formed in contact with it, this acid will decompose the sulphuret, will disengage sulphuretted hydrogen gas with the smell of rotten eggs, and will form carbonate of lime. These several changes take place frequently in the soil, and are probably connected with the way in which gypsum acts in some soils in supplying sulphur to the plant (see page 5).

3°. Gypsum dissolves in water, and is present, as I have said, in springs. But pure water cannot take up more than one five-hundredth part of its weight, or one pound for every fifty gallons.

SECTION II.—USES OF GYPSUM FOR AGRICULTURAL PURPOSES.

1°. *As a manure* gypsum, has been long employed more or less extensively. In some districts and countries it is little used or esteemed, while in others it is applied every year to every crop and by almost every farmer.

In Scotland it is in little request, and the same is true of Ireland generally and of the north of England. In the south of England it has in some places been applied with advantage to grass land, at the rate of 2½ cwts. per acre, for thirty-five years in succession. In North America, especially in the New England states, it has been, and I believe is now, employed more extensively than in any other part of the world. Why this diversity of practice and of opinion in regard to gypsum prevails will be explained in the following section.

* Sulphuret of calcium is merely the sulphate of lime deprived of its oxygen.

To grass lands, and especially to clovers, it has been most abundantly applied in Europe. Upon beans, peas, and other leguminous crops also, experience seems to show that it exercises a specially beneficial action. In the United States of America, however, it is applied with advantage to every crop.

In Europe it is generally dusted over the crops in early spring and in moist weather. In America it is usually sown with the seed, or in the case of Indian corn and potatoes, is put into the holes or the drills along with the seed.

When applied as a top-dressing in spring a good deal appears to depend on the time selected for the application. Körte top-dressed a field of clover with it, dusting it over different parts of the field at different times, beginning with the 30th of March. The following comparative results were, reckoning the weight of clover from an equal surface undressed, obtained at 100 lbs. :—

The undressed part yielded	100 ℔s.
Dressed on 30th March	132 ℔s.
Dressed on 13th April	140 ℔s.
Dressed on 27th April	156 ℔s.

Thus the later dressing had greater effect than the earlier one. The rain that falls in the month of March, in Prussia, where this experiment was made, may be different from what usually falls in this country, and may therefore both affect the state of growth of the clover at that season, and the chance of the gypsum being either dissolved or washed away. Still the result of this experiment seems to show that the application of a given quantity of gypsum to a crop of clover is most likely to produce a good effect if applied when the leaves are pretty well developed.

2°. *To dung-heaps and tanks to fix the ammonia*, gypsum is now extensively applied, and is much recommended.

When manure ferments ammonia is produced, and gradually collects in stables, dung-heaps, and liquid manure tanks, in the form of carbonate of ammonia (common smelling-salts). This substance being volatile, readily rises in the form of vapour, and escapes into the air. It is valuable, however, as a manure, and ought, if possible, to be arrested.

When a solution of gypsum in water is mixed with one of carbonate of ammonia, sulphate of ammonia is produced, and carbonate of lime falls. The sulphuric acid leaves the lime, and combines with the ammonia. The same takes place on a moist stable floor or in a moist dung-heap, when finely powdered gypsum is strewed upon them. The sulphate of ammonia thus formed is not volatile, and therefore has no tendency to escape into the air. The ammonia is, therefore, said to be fixed, and is in reality by this means retained in the moist manure.

Two or three hundred-weight of gypsum is sufficient to produce this effect upon twenty tons of farm-yard dung. But it must be borne in mind that in the absence of water the gypsum is wholly inert, and that if the manure become dry, the sulphuric acid again leaves the ammonia and re-unites with the lime—thus re-producing carbonate of ammonia, which begins, as before, to rise in vapour and to escape into the air.

When introduced into manure tanks it can scarcely act, therefore, unless it be in a state of solution. It ought, consequently, to be thrown into them in small quantities at a time—in the form of a very fine powder—and if possible the whole ought to be occasionally stirred.

A manure called *urate* is made by adding gypsum in this way to urine, and collecting and drying what falls. Thus made, it consists for the most part of unchanged gypsum, with a little phosphate of lime and organic

matter. Many of the preparations now known or sold under this name, are mixtures prepared in other ways, of which the composition is unknown to the buyer, and is not therefore to be relied on.

SECTION III.—THEORY OF THE BENEFICIAL ACTION OF GYPSUM AS A MANURE.

The theory of the beneficial action of gypsum as a manure, and the cause of the different opinions in regard to its virtues which are entertained in different districts and countries, will be explained by a reference to its chemical composition, and to the properties we have already shown it to possess.

1°. Dry or burned gypsum contains 41½ per cent. of lime. When a soil, therefore, is deficient in lime, or when the crop growing upon it is likely to be improved by placing this substance more abundantly within its reach, the application of gypsum will be beneficial. It will act in this case as an equal dose of lime in any other form would do, and very nearly in the same way.

When mixed with a soil containing much animal or vegetable matter, or with a manure or compost heap, it is gradually changed into carbonate of lime, as I have explained in a previous section. In this state of carbonate it acts as so much chalk or long-slaked lime would do.

In this view, when we add gypsum we are in reality liming our lands, and I have no doubt that the good effects observed from the addition of it in large quantities year by year in some countries is owing to the unfrequent application of lime in other forms. And on the other hand, that gypsum has little marked effect in most of the well-cultivated parts of our island, is in many cases to be ascribed to the frequent addition of

lime in its more common states of quick-lime, chalk, marl, or shell sand.

In the county of Durham lime is often added before the corn crop, not because of the good it is expected to do to the corn itself, but because it will improve the clover which follows it. Gypsum applied to the clover itself might do the same, but if so it would only be fair to conclude that the lime contained in the gypsum was concerned in producing this good effect.

2°. But dry gypsum contains also 53½ per cent. of sulphuric acid—a considerably larger proportion of the acid than it does of the lime. To this acid it is equally certain that a portion of the effect of gypsum is to be ascribed. If, indeed, when compared with chalk or quick-lime, it produce any special effect upon our crops or soils, it is reasonable to ascribe that effect to the *special* ingredient sulphuric acid, which forms so large a proportion of its whole weight.

We have seen in a previous chapter (p. 165) that sulphur is one of the substances which plants require for their support, and which they draw from the soil. Two facts, therefore, appear certain. First, that where soils are deficient in those forms or combinations of sulphur which are fitted to enter into and thus to minister to the growth of plants, the addition of gypsum may be expected to produce good effects. And second, that if any of the crops we grow, specially require sulphur more or in greater quantity than others, to these crops gypsum ought to be especially useful.

Upon a soil deficient in sulphur, all crops will be benefitted by the sulphuric acid which the gypsum contains. Where land is not regularly limed, it is possible, therefore, that both the constituents of the gypsum may act beneficially, and thus an amount of improvement may follow from it which can never be looked for when the land contains either lime or sulphur enough to meet all the demands of the growing plant.

We have said that the action of this substance is more marked upon clovers and leguminous plants in general than upon other crops. These crops, so far as our present knowledge goes, appear to require more sulphur for their natural growth, and for the completion of their several parts than our corn crops do, and hence the special action of gypsum upon them is ascribed to the special ingredient sulphuric acid, which is a constituent of gypsum.

Thus there are four degrees of beneficial action which gypsum may exhibit when applied to our fields.

First, its greatest possible effect when a crop requiring much lime and sulphur is grown, and when the soil is at the same time deficient both in lime and in sulphuric acid.

Second. An effect less in degree when crops of other kinds are grown upon a soil deficient in both lime and sulphur.

Third. A less observable effect still when the soil abounds in one of these two substances and is deficient in the other. And

Lastly, when the soil is neither deficient in lime nor in sulphuric acid. It may happen that in this case no sensible effect at all is observed on the application of gypsum.

It is quite clear to the reader that such natural variations in the circumstances under which gypsum is used, readily account for the different results obtained by different experimenters in different countries and in different districts.

I have shown that upon land limed in the ordinary way gypsum may exhibit much less action than upon soils to which no other form of lime is usually added. It can in the former case be expected to act only by means of its sulphuric acid.

But in land regularly limed it may happen that even

this sulphuric acid is not required. Most limestones contain a proportion—some a very sensible proportion of iron pyrites in which sulphur is a large constituent.* When thrown into the kiln this sulphur is expelled from the iron, is burned, and in part at least is laid hold of and retained by the lime, and ultimately forms gypsum. Such lime when slaked contains, therefore, a certain proportion of gypsum, and it may be that the large doses of lime we are in the habit of applying in this country may convey to the land so much of this compound as to render it entirely unthankful for or unaffected by the two or three cwts. per acre of gypsum which are usually dusted on as a top-dressing.

Hence upon land which is regularly limed it will always be a matter of doubt whether gypsum added alone will prove profitable to the farmer. Trial only can determine its value. If it fail, an analysis of the burned lime usually added may explain the cause of the failure.

I have said that if the land be deficient neither in lime nor in sulphuric acid, no good effect at all *may* follow from the application of gypsum to the crop. Some might be inclined to say that there can be no doubt in this case. If there be enough in the soil no good can follow from the addition of more. And yet that is not necessarily so. A substance may produce a good effect when strewed on the surface, which it can not do when buried in or mingled with the soil.

Thus it has been observed by Peschier, that when lime is sprinkled over the leaves of growing plants, it is gradually changed into carbonate, the sulphuric acid being most probably absorbed by the leaves. Now, when thrown as a top-dressing upon green grass or clover, it may be decomposed in this way by the young

* Iron pyrites consist of 54¼ per cent. of sulphur and 45¾ per cent. of iron.

leaves. And, as we know that sulphuric acid in the sap of plants can produce—nay, as we believe at present really does produce—important chemical changes, even when it does not itself enter as a constituent into the parts of plants; it is far from improbable that a good effect may follow from this form of its action when applied as a top-dressing, though there be an abundance of gypsum all the while in the soil.

Again, the explanation of the good effects of gypsum given by Liebig some years ago was, that it absorbed and fixed ammonia from the atmosphere. This he supposed it to do chiefly and almost solely while it lay on the surface exposed to the action of the air. No quantity covered up in the soil, however large it might be, could perform the function thus ascribed to it. This explanation of the good effects of gypsum is no longer insisted upon. It is untenable, among other reasons, because the atmosphere contains little ammonia to fix—because if it did, the gypsum applied would not fix enough to account for the increased produce often raised by means of it—and because if this were the true explanation, gypsum strewed on the surface ought to be beneficial to all soils, and almost equally so to all crops, which is far from being the case. This supposed action of gypsum, however, presents a very clear illustration of my statement, that gypsum may benefit the crop, though both lime and sulphur abound in the soil in which it grows.

I add only one other remark in regard to the action of gypsum in the soil. I have stated that under certain conditions of moisture, gypsum, when in the state of fine powder, will fix the ammonia of stables, compost heaps, fold-yard manure, and liquid manure tanks. Ammonia is produced naturally in the soil, and gypsum, if present, as it usually is in most soils to a certain amount, will fix it there as it does in the com-

post heap. When rain comes, or when the soil is moist enough to dissolve the gypsum, the carbonate of ammonia of the soil decomposes it as already described, and forms sulphate of ammonia. It is very probable that this salt enters into the roots of plants, and thus supplies them with both the sulphur of its acid and the nitrogen of its ammonia (p. 165)—the carbonate of lime formed at the same time remaining in the soil to perform those numerous other useful functions for which we have seen it is principally intended.

If the soil be too dry this natural interchange between the constituents of the carbonate of ammonia and the gypsum does not take place; or if it *become* too dry afterwards, the change is undone, and carbonate of ammonia and sulphate of lime are formed anew.

SECTION IV.—USE OF MIXTURES OF GYPSUM AND COMMON SALT.

Experiment has shown that in practical agriculture more certainly good results are to be expected from the application of mixed manures to the land than from the use of any substance laid on alone.* The reason of this is easily seen. The plant requires many things from the soil; by adding two or more, therefore, we are more likely to hit upon what the soil is in want of than if we add one only. And if we should happen to apply at once two substances which the plant has hitherto had difficulty in obtaining, we reap a double benefit.

In many inland districts the use of common salt is found to be very advantageous when applied alone in promoting the growth both of green and corn crops, and in adding to the weight of the grain. Mixed with

* See the author's *Lectures on Agricultural Chemistry and Geology*, 2nd Edition, p. 634.

gypsum the action of the latter upon leguminous crops appears to be greatly increased. William Alexander, Esq., now of Ballochmyle, dressed an apparently worthless crop of young beans with a mixture of 2 cwt. of gypsum and one of common salt per acre. The effect was almost marvellous, and instead of a bad crop, his beans were the admiration of the country. He found a sensible effect produced by this mixture, even after the beans were in flower.

I draw the attention of my readers to the effects of this mixture in a separate section with the view of inducing some of them to test its virtues by repeating the experiment.

SECTION V.—USE OF MIXTURES OF LIME AND SALT.

For the same reason I draw attention more fully to the alleged virtue of admixtures of lime and salt. I have frequently, and especially for the destruction of insects, recommended the mixture of a certain quantity of common salt with quick-lime before it is laid upon the land. This may be done in either of three ways.

1°. The salt may be dissolved in water, and the solution used for slaking the lime.

2°. The quick-lime and salt may be mixed together, and then either slaked with water or left to fall spontaneously.

3°. The lime after being quickly slaked may be mixed with the salt in alternate layers, and the whole then covered over and left for some time in a heap.

The first and third of these methods are better than the second.

The quantity of salt recommended by some is as much as one-half or one-third the weight of the lime, but that of course can only be when the applications of lime are comparatively small. It is only on very foul land in-

deed, on land supposed to be very deficient in alcaline matter, and where it is laid on in the autumn or during a naked fallow, that the quantity of salt should be allowed to exceed half a ton per acre. Four or five hundred-weight will generally be enough, repeated every two rotations when the practice is to lime at such intervals.

When common salt is mixed with the quick-lime in the way above-described, it is in part converted into caustic soda. Hence when the mixture is laid upon the land it not only places soda abundantly within the reach of the plant, but it also brings in contact with the organic matter of the soil a substance (soda) which acts upon it more energetically than lime does, and thus more quickly prepares it for entering as a useful food into the roots of plants. I have already in a previous chapter (p. 131) explained what this action of alcaline substances is.

The use of lime and salt has been frequently recommended by Mr. Cuthbert Johnson and others, and its virtues in the proportion of one of salt to two or three of lime, have more lately been experimentally tested and recommended by Mr. Huxtable. It seems to be particularly adapted to deaf soils, as they are called, to such as are covered with moss, and to reclaimed and drained peat-bogs. Upon chalk soils, also, the mixture has been found very beneficial, and it is deserving of an extensive and careful trial. When mixed for the purposes of an ordinary liming, the usual dose of lime may be somewhat diminished.

SECTION VI.—USE OF SILICATE OF LIME—THE SLAG OF THE IRON SMELTING FURNACES.

Much lime is used in the smelting of our clay iron stones, and the first grey or bluish slag which runs off

is either altogether allowed to accumulate in heaps or is in part employed for mending the roads.

The composition of a slag of this kind from the iron works near Beith, in Ayrshire, was found in my laboratory to be as follows:—

Lime	39·47
Magnesia	2·75
Alumina	25·36
Silica	32·19
	99·77

The proportion of lime in this slag is nearly as great as in gypsum. Both it and the magnesia are in combination with the silica forming what are called silicates. In the soil these silicates are slowly decomposed by the carbonic and other acids which come in contact with them, and thus they are enabled to yield lime and magnesia as well as silica, in a soluble state, to the growing plant. The acids contained in very wet and in peaty soils are especially fitted to decompose them, and hence upon such soils these slags, if crushed to powder, ought to produce a marked beneficial effect.

Some of our iron works are situated in the immediate neighbourhood of tracts of such land. It is very desirable, therefore, that experiments should be made with it, and if found, as I think it will, to be really beneficial, that it should not be left uselessly to accumulate as it has hitherto done.

CHAPTER XII.

Use of lime in the state of phosphate. Composition of burned bones, of bones in their natural state, and of boiled bones. Use of bones as a manure. Theory of the fertilizing action of bones burned and unburned. Mixture of bone-dust and common salt. Modes of reducing bones by grinding, fermenting, dissolving, &c. Bi-phosphate of lime. Modes of applying dissolved bones. Phosphating compost and manure heaps. Phosphate of lime prepared from human urine. Proportion of phosphate of lime contained in corals, chalks, marls, and limestones. Influence of previous liming on the apparent action of bones. Concluding observations.

One of the most important forms in which lime is applied to the land is that of phosphate. To complete our view of the uses of lime, therefore, it will be necessary to consider the composition and properties of the phosphate, the different states in which it is laid upon the land, and the purposes it serves in reference to the growth of plants.

SECTION I.—COMPOSITION OF BURNED BONES, BOILED BONES, AND BONES IN THEIR NATURAL STATE.

It is chiefly from the bones of animals that the farmer derives the supplies of phosphate of lime he is in the habit of laying upon his land.

1°. *Burned bones.*—When bones are burned in the fire they lose about one-third of their weight, become light, white, and porous, but retain their original form, and nearly their original bulk. The burned bone is easily reduced to powder, and consists very nearly of

	per cent.
Phosphate of lime (or bone-earth)	82
Phosphate of magnesia	5
Carbonate of lime and a little fluoride of calcium	8
Soda and common salt	5
	100

The carbonate of lime is sometimes greater than is here represented—the composition of the burned bone varying a little with the kind of bone and with the animal from which it is taken—but the above, as a mean result, is sufficiently correct for all practical purposes.

About five-sixths of all that the bone leaves when burned consists, therefore, of phosphate of lime. This phosphate in a hundred parts is composed of

	per cent.
Lime	51½
Phosphoric acid	48½
	100

Every hundred pounds of burned bone, allowing for what is contained in the phosphate of magnesia and in the carbonate of lime, contains, therefore, about 46 pounds of lime and 43 pounds of phosphoric acid.

2°. *Boiled bones.*—When bones are boiled for a length of time in water they part with a great deal of fat, which floats on the top of the liquid, and of gelatine or glue which is dissolved by the water. In Manchester and other manufacturing towns, bones are boiled in this way for the preparation of a size used in stiffening calicos and other goods. The bones when thus exhausted by boiling, still contain much animal matter or gelatine, but they are thoroughly impregnated with water, and therefore, when laid upon the land, decompose more readily and are more easily attacked and taken up by the roots of plants. That they lose by the boiling, however, a part of their value as a manure is shown by the fact that when the size, even after it has become too weak for the manufacturer, is applied in the liquid form to grass land, it promotes the growth of the herbage in a remarkable degree.*

* Thus, Mr. Gardner, overseer to Mr. Fleming, of Barochan, in Renfrewshire, found that a field of sown grasses, which in the un-

The composition of boiled bones, so far as I know, has never been investigated. In the state in which they are sold they always contain a large proportion—sometimes half their weight—of water. This makes their real manuring value to the farmer very much less than that of dry bones. The true money value can only be determined for each sample by drying it—in a moderately hot oven for instance—and thus estimating the proportion of dry matter it contains.

3°. *Bones, in their natural state*, contain all that is extracted by boiling and all that is destroyed by burning them. Those of man, the ox, and the sheep usually contain of—

Water	7 to 20 per cent.
Fat	15 to 30 per cent.
Dry matter	50 to 80 per cent.

As bones are sold and crushed at our bone mills, they contain about 10 per cent. of water and a proportion of fat which has never been rigorously determined. The older they are, the less fat is usually to be expected in them. The proportion of fat which may exist in them is of less moment to the farmer, as it is not supposed to contribute much to their fertilizing action. In too large quantity its action may be injurious, as it may retard the decay of the bones when they are laid upon or buried in the soil.

When dry, and free from fat, ox bones consist in the hundred parts of about—

Cartilage (gelatine or glue)	33⅓
Earthy matter (burned bone)	66⅔
	100

dressed parts yielded only 26½ cwts. of hay per acre, gave 47¾ cwts. when watered with 200 gallons per acre of a liquor in which bones had been boiled.

—Or more particularly of—

Gelatine	33¼
Phosphate of lime	55½
Phosphate of magnesia	3
Carbonate of lime	3¾
Fluoride of calcium	1
Soda and common salt	3½
	100

In round numbers, therefore, bones as they are laid on the land contain about—

Water and fat	15 per cent.
Gelatine	27 "
Lime	28 "
Phosphoric acid	26 "

It is upon the presence of these three substances—the gelatine, the lime, and the phosphoric acid—that the fertilizing action of bones *almost* exclusively depends; the word almost being intended to imply that the small proportions of magnesia and soda are not without their useful effect.

SECTION II.—USE OF BONES AS A MANURE FOR VARIOUS CROPS.

It is of little importance to us when bones began to be employed for agricultural purposes. In the eighth chapter of Jeremiah, first and second verses, the prophet in speaking of the bones of the Kings of Judah, &c., says,—"They shall not be gathered nor be buried: they shall be for dung on the face of the earth."

Whether this passage means that at the period when Jeremiah lived the value of bones as a manure was known to the Jews it is difficult to determine. It is probable, however, that though comparatively little used their value has been long known to the more instructed farmers in many countries. In Great Britain and in some

other countries they form at present the most important, and the most highly valued of all our so called artificial, portable, or extraneous manures.

They have hitherto been employed either as a manure for the turnip, beet, mangel wurtzel, and carrot crops, or as a top dressing for grass, chiefly pasture land. The method of dissolving and reducing them by means of acid is, however, gradually bringing in their use as applications to other crops. They are now sown with advantage along with the seed corn, or are applied as a top-dressing to the young crops in spring.

When first introduced to general notice in England, some sixty years ago, it was not unusual to apply as much as 80 bushels an acre, and in some districts when applied to the land for the first or second time, as much as 40 bushels an acre is still used to raise the turnip crop. From 16 to 20 bushels of bone-dust, however, are now commonly drilled in with the turnip seed in our long cultivated arable districts and of dissolved bones as little as 6 or 8 bushels have been found to give a luxuriant return.

As an application to grass land, it is in Cheshire that their effects have been most remarkable. They are laid on to the extent of a ton or more per acre, and they may be said almost to renovate the pasture—increasing its value from five or ten to thirty or forty shillings per acre. Their good effects continue visible also for a long series, as much as 20 or 30 years.

It is an interesting, though by no means an inexplicable fact, that similar good effects have not been found to follow from their application to grass land in other parts of the country. The reason of this will appear in the following section.

SECTION III.—THEORY OF THE FERTILISING ACTION OF BONES, BURNED AND UNBURNED.

As in the case of gypsum, the theory of the fertilizing action of bones becomes apparent when we consider, on the one hand, what the plant demands from the soil, and, on the other, what the composition of bones shows that they convey to it.

Unburned bones in the state in which they are usually applied to the land consist, as we have seen, of lime, phosphoric acid, and cartilage, in nearly equal proportions. Burned bones contain no cartilage. They consist chiefly of lime and phosphoric acid, also in nearly equal proportions.

1°. *The lime* they contain cannot fail to be useful to a certain extent in supplying this kind of food in a form of which plants can avail themselves. But the quantity of this ingredient which is present in 20 bushels of bones —supposing them to weigh 50 lbs. a bushel—is little more than two hundred-weights. This may supply all that is required actually to feed the plant with lime, but it is insufficient to produce those other special effects—such as removing acid and decomposing organic matters—which in the preceding chapters have been described as resulting from the application of quick-lime to the land. Still the lime conveyed to the soil by bones, must assist in bringing about the results which are seen to follow from their use. The proportion of this effect actually due to the lime will be greatest when the soil is poor, and least when it is already rich in lime. In some cases the soil may be already so well supplied with lime that no good effect can be ascribed to that which the bones laid upon it may contain. But in such a case—on well limed land for example—we should expect also that bones would never be found to produce what may be considered as their greatest possible ef-

fect. And in Cheshire experience confirms this expectation.

2°. *The phosphoric acid.*—Of the various substances which plants draw from the soil, phosphoric acid is one which is indispensable to them all. Some plants and some parts of plants require it in larger quantity than others, but no useful plant, so far as is yet known, and no part of a plant can be perfected in growth without the presence of this substance.

The crops of a four-year's rotation—wheat, barley, turnips, clover—of average yield, require and carry off from the soil about 120 lbs. of phosphoric acid. Land of average quality, therefore, kept in arable culture, yields annually to the crops grown upon it about 30 lbs. of this acid. To supply this quantity, were none of the crops returned again to the land in the form of farm-yard or other manures, the yearly addition of above one hundred weight (115 lbs.) of common bone-dust would be required. It cannot be doubted, therefore, that one of the sources of the fertilizing action of bones is to be sought for in the phosphoric acid they contain and which they supply to the growing crops.

And as this acid serves no other known purpose in the soil than that of supplying the wants of the plant, it is obvious that a smaller proportion of it in the soil, or a smaller addition of it to the soil, will produce the greatest effect possible—than would be the case with lime. If all the plant requires be readily supplied, any further addition to the soil will be matter—for the present thrown away. It is because so small a quantity is fitted to yield this supply to the plant, which yet could not grow without it, that the beneficial effects of bones are as a general rule to be ascribed more to their phosphoric acid than to their lime.

The effect of this ingredient, I need scarcely add, will be greatest when it is least abundant in the soil, and

that if lime be deficient in it also, the influence of the bones will be still more apparent.

3°. *The animal matter or gelatine.*—Plants and soils, like bones, contain a considerable proportion of matter which burns away and disappears when they are kindled or exposed to the red heat of an open fire. Of the organic matter which thus burns away, a considerable proportion resembles the animal matter of the bones in containing nitrogen. This nitrogen plants derive for the most part from the soil, and the combustible part of the bones during its decay in the soil is fitted to yield it to their roots. Thus to the animal matter also a part of the good effect of bones upon the land is to be attributed, and this portion of their effect will be greatest when the soil is poorest in those forms of matter which are fitted to yield nitrogen to the extending roots.

As in the case of gypsum, therefore, the action of bones upon the land will manifest itself in different degrees. It will be greatest where all the three principal constituents are deficient, next in degree where some one of them is already abundant, still less apparent where two of them are plentiful in the soil, and wholly without effect where all its constituents already exist abundantly in the land.

SECTION IV.—MIXTURE OF BONE DUST WITH COMMON SALT, PEAT ASHES, WOOD ASHES, COAL ASHES, SAND, SAW-DUST, ETC.

Instead of applying crushed bones or bone dust alone, many prefer to mix them with other substances by which their action is believed to be increased.

Common salt at the rate of one or two hundred weights per acre is drilled in along with them by some farmers, and upon some soils, with good results.

Peat ashes by others are mixed with the bones and

left for a time to heat before they are applied, and in some districts where such ashes abound this practice is general.

Wood ashes which are less plentiful among us, are also employed in this way. Exhausted wood ashes—or *leached* as they are called in America, when water extracts nothing more from them—may likewise be recommended for this purpose.

Coal ashes mixed with bone dust, help to distribute it more widely and evenly. They contain also gypsum and some other substances which are useful to plants.

Sand even, mixed with the bone-dust in a moist state, in equal bulk, and allowed to lie in a heap for some time before application, is found to be very useful.

Saw-dust moistened and fermented with the bones also greatly hastens and increases their apparent action.

All these substances and methods aid or increase the action of bones. First, mechanically, by tending to facilitate and render more rapid the crumbling down or disintegration of the generally dry manure. Second, practically, by bringing within the reach of the young plants a supply of other things not contained in the bones themselves, and which the roots of plants must obtain from the soil.

SECTION V.—MODES OF REDUCING AND DISSOLVING BONES. USE OF SULPHURIC AND MURIATIC ACIDS.

Bones when laid upon the land in large pieces decay very slowly and exercise comparatively little influence upon its fertility.

1°. When crushed in bone mills they can be spread more uniformly, diffused more widely, and covered up more completely. They are thus enabled to soften and decay more rapidly, to be brought more generally within the reach, and to be more easily acted upon by the roots of plants.

2°. When boiled this decay is more rapid, and hence where boiled bones are to be procured, many farmers prefer them. This is especially the case in Cheshire, where pieces of dry bone are often found in the soil, apparently unchanged, years after they have been applied.

3°. When thrown into a heap and covered over with earth the crushed bones heat, soften, and crumble down. A little of their virtue, as is the case in boiling, may be lost in this way, in consequence of the fermentation, but because of their more rapid action when thus reduced, this method of heating is in some counties very generally adopted. I shall return to this method in a succeeding section.

4°. Mixed with moist peat ashes, sand, or saw-dust, as described in the previous section, they also heat and crumble rapidly, and hence the favour which this practice finds, especially in our southern counties.

5°. But the method of reduction hitherto found most effectual is that of dissolving them more or less completely by means of acid.

Two acids have been employed for this purpose, the muriatic acid or spirit of salt and the sulphuric acid or oil of vitriol. The latter has found most general acceptance, and appears to produce a more fertilizing manure.

The crushed bones are put into a wooden or stone trough, and from one-fourth to one-half of their weight of acid diluted with two or three times its bulk of water, is poured upon them. They boil up for a while and gradually dissolve. In a few days with occasional stirring, the lumps of bone disappear, and the whole has assumed the appearance of a pulpy mass. If the manure is to be applied in a liquid form, this pulpy mass is now mixed with a sufficient quantity of water, and is distributed by the liquid manure cart. If it is to be drilled in, it must be dried by mixing it with a quantity

of fine bone-dust, dry soil, crushed peat, peat ashes, wood ashes, saw-dust dried brown, wood or animal charcoal, bran, chaff, oat-shellings, gypsum, &c. Quick-lime, chalk, or marl, had better not be employed for this purpose, as they tend to render the phosphoric acid of the manure less soluble in the soil.

Some make a conical hole in a heap of peat or coal ashes, put the bones into this hole, pour the acid upon them and cover the whole up. The bones crumble and after a few days disappear. The whole is then mixed together by once or twice turning over.

In practice it is found that the addition of a small proportion of salt to the mixture of acid and bones, makes the solution more rapid and complete.

Bones thus prepared are known indifferently by the names of dissolved bones, sulphated bones, super-phosphate of lime, and bi-phosphate of lime. The last two are used by dealers and manufacturers, but are incorrect as names for the mixed substance obtained.

SECTION VI.—COMPOSITION OF THE SO CALLED *super* OR *bi*-PHOSPHATE OF LIME, MODES OF APPLYING IT, EFFICACY OF DISSOLVED BONES AS A MANURE, AND CAUSE OF THIS EFFICACY.

When thus dissolved or reduced by means of sulphuric acid, a part of the lime of the bones combines with the acid and forms gypsum. The remainder is consequently combined with a larger proportion of phosphoric acid than before. Hence the name *super*-phosphate, and *bi* (*bis*-twice) phosphate improperly given to the prepared manure. It is a mixture of gypsum and this super-phosphate, with all the animal matter of the bones which by the action of the sulphuric acid is also reduced to a minutely divided state. And although there is reason to believe that a super or bi-phosphate of lime would alone

benefit many soils and crops, yet the special fertilizing action of dissolved bones depends upon their being a mixture of all the three substances I have mentioned.*

1°. *Modes of applying the manure.*—To the turnip crop it has occasionally been applied in the liquid form with great success. But this method is troublesome and tedious. It is more usual, therefore, to dry up the solution or the pasty mass in one of the ways I have already described, and to apply it with the drilling-machine. To grass and young corn it is applied as a top-dressing, sown broadcast with the hand.

2°. *Efficacy of dissolved bones.*—The efficacy of dissolved bones may be considered either absolutely or in comparison with bones which have not been so prepared. The following table shows the result of a trial of their effect upon wheat when applied as a top-dressing in spring, compared with farm-yard dung and guano:

	Cost.			Produce in bushels.
	£.	s.	d.	
Unmanured	0	0	0	29
20 tons dung	4	10	0	40
3½ cwt. guano	2	4	0	40
6 cwt. dissolved bones	2	8	0	53

This table shows, first, that the dissolved bones were absolutely very beneficial, since they raised the produce from 29 to 53 bushels of wheat an acre; and second, that they were comparatively more beneficial than an equal value of farm-yard manure or of guano, which increased the produce only to 40 bushels.

* What is sold in the manure markets is not always bones dissolved in sulphuric acid,—it is sometimes produced by dissolving burned bones in sulphuric acid—in that case it consists of a mixture of bi-phosphate of lime with gypsum. Sometimes it is manufactured by dissolving Saldanha Bay guano in sulphuric acid; in that case it is a mixture of gypsum and bi-phosphate of lime with a little organic matter. But as a generally useful manure, and one of which the composition is most constant, bones dissolved in sulphuric acid is the most valuable of these several preparations.

Again, compared with undissolved bones, Mr. Hannam found that, upon a field of turnips,

	ton.	cwt.
16 bushels common bone-dust gave	10	3
8 bushels dissolved bones	15	0
4 do. do.	13	7
2 do. do.	10	12

—so that in this case as large a crop of turnips at least was obtained by the use of two bushels of dissolved bones as by sixteen of dry bone dust.

Numerous other experiments have been followed by similar results, and it is now very generally believed that this is the most economical and most widely useful form in which bones can be used as a manure for any crop. Of the comparative efficacy of bones reduced by fermentation, I have treated in the following section.

3°. *Source of this increased efficacy.*—There are several apparent reasons why dissolved bones should produce this greatly increased effect—

1°. They are minutely divided, and therefore can be uniformly diffused through the soil and over a much larger area.

2°. Their constituents are all rendered much more soluble, and therefore more easily taken up by plants.

3°. None of the bones escape decomposition as in some soils dry bones often do; there is, therefore, no waste.

4°. The presence of sulphuric acid also introduces a new element of success. If the soil or the plant is in a condition to be benefitted by this acid, the single effect of the bones must be augmented by its presence. And this is more likely to be the case, inasmuch as sulphuric acid not only feeds the plant by entering into and becoming part of its substance, but also when circulating in the sap produces certain purely chemical effects which are favourable to that change of materials by which the growth of plants is promoted.

5°. Again, when common salt is employed in aiding the solution of the bones, other substances which plants require are introduced into the manure, and thus the chances of improvement from the use of it are still further increased.

SECTION VII.—ECONOMY OF FERMENTED BONES.

Though experience appeared to have shewn the superior efficacy of bones dissolved or reduced by means of acid, it has lately been stated by Mr. Pusey and others, that the old method of fermenting bones with ashes, sand, or saw-dust—so long practised in many districts—is, after all, as effectual, and, if so, more economical than the new one of dissolving them by means of acids.

In 1845 he tried bones mixed in this way, and fermented, against dissolved bones, upon turnips, and obtained from each manure an equal return.

In 1846 he mixed moistened crushed bones with half their bulk of sand, allowed them to heat, ferment, and fall to powder, and applied them against unaltered crushed bones, and sulphated or dissolved bones. Three bushels of the mixture with sand contained more than two bushels of bones. The results in two experiments were as follow:—

	£.	s.	d.		tons.	cwts.
1°.—17 bushels of bones, costing	2	6	9	yielded	13	5
4½ do. of sulphated bones..	1	2	9		14	5
8½ do. of bones and sand...	1	0	9		13	5
2°.—25½ bushels of bones, costing	3	10	0	yielded	14	5
7½ do. of sulphated bones..	2	3	0		14	5
12¾ do. of bones and sand, containing 8½ do. of bones	1	11	0		17	1

Mr. Day also found that 16 bushels of unprepared bones, 4 bushels of heated bones, and 2 bushels of sulphated bones (or super-phosphate), gave each the same yield of Swedes.*

* Journal of the Royal Agricultural Society, VIII., p. 418.

These results are certainly very favourable in an economical point of view, and are highly deserving of repetition. They do not show, however, that the same weight of bones goes so far in the fermented as in the dissolved state—only that at the present price of acid an equal weight of crop can be raised by fermented, at a less cost, than by dissolved bones.

In the previous section I have ascribed a part of the virtue of dissolved bones to the sulphuric acid they contain. Granting this to be the case, however, there are many soils in which sulphuric acid is not deficient, and to crops grown upon which, therefore, artificial additions of this acid will be of no benefit. On such soils sulphated bones may have no superiority over finely fermented bones, because of the sulphuric acid they contain, though upon others, again, a considerable benefit may be produced by it. It is to be wished, therefore, that experiments should be made upon various soils with this consideration in view. Should fermented bones, though confessedly superior to dry crushed, but otherwise unreduced bones, be found on some soils to equal, while on others they are decidedly inferior in efficacy to dissolved bones, it may still turn out that the method of dissolving bones is to be recommended as a general practice. Repeated experiments, however, will by and bye bring out the truth. Agricultural experimenters are fond of novelty and change, but truth in theory and economy in practice, are only to be discovered by careful and frequent repetitions of the same trials, in more varied and accurate ways.

It is not to be left out of view that the state of the animal matter in the bones is of importance to their action as a manure; and that when fermented it *may* be more grateful to plants than when reduced by means of an acid.

SECTION VIII.—HOW TO IMPREGNATE COMPOST HEAPS OR FARM-YARD MANURE WITH AN ADDITIONAL QUANTITY OF PHOSPHATE OF LIME.

Bones contain, as we have seen, phosphate of lime in large quantity. This substance is very valuable to plants, and by means of sulphuric acid and a little salt—as above described—it can readily be obtained in a liquid form.

Composts or mixings of various kinds have been long and beneficially employed as applications to the land. But they are in general comparatively poor, and require to be laid on in very large quantities. It has been suggested, therefore, that by means of solutions of dissolved bones they might be watered and enriched so as greatly to increase their general efficiency, and the number of purposes for which the farmer could directly employ them. There is no doubt, indeed, that both liquid bones and liquid manures of other kinds might be thus abundantly worked up in a way likely to be profitable to the practical farmer.

Again, farm-yard manure, by washing with rain or by fermentation, is too often exhausted of the materials of bones, which it to a certain extent naturally contains. It has been found, by experience, in some localities, that the addition of farm-yard manure to the land beyond a certain quantity, is attended with little comparative advantage, and that half dung with half bones or guano is more generally profitable to the farmer. Instead of applying this manure separately, therefore, and having thus two applications to make to the land, some recommend to *phosphatise* the manure more highly by impregnating it with dissolved bones before conveying it to the field. In theory this is by no means objectionable, though in practice the difficulty of thoroughly mixing the phosphates with the manure, and the after-chances of loss by drainage, the washing of the rains,

&c., may be considered likely to lessen very materially any advantage that could be reasonably expected from this method. Still when parties have the opportunity, all such suggestions are deserving of trial, and may lead to practical good.

SECTION IX.—PREPARATION OF PHOSPHATE OF LIME FROM HUMAN URINE.

Phosphoric acid exists in human urine. The addition of lime-water or of milk of lime to it causes the production of phosphate of lime, and this has been recommended as a useful method of at once preparing what, rightly used, may be of great value to the land, and of saving at the same time a portion of what hitherto has been allowed so generally to run to waste.

Dr. Stenhouse found a precipitate which he obtained in this way from human urine, to consist of

	In the precipitate dried at 212.	In the precipitate dried in the air.
Water and organic matter	12·66	56·90
Nitrogen	0·88	1·91
Lime	44·96	
Magnesia	1·32	41·19
Phosphoric acid	40·18	
	100	100

Such a substance as this will partake very much of the efficacy of bones as a manure. It contains less nitrogen, but the proportion of phosphate of lime is large. The danger in trusting to the manufacturer of such things is, that the proportion of lime he adds to or mixes with it may vary, may even become very much too great, and thus its value to the farmer be proportionably diminished.

The practical man may, however, prepare this substance for himself by adding one pound of newly and finely slaked lime to every ten gallons of human urine

—that of the cow and the horse containing no phosphoric acid*—and mixing well together.

SECTION X.—PROPORTION OF PHOSPHATE OF LIME CONTAINED IN MARLS, CORALS, CHALKS, AND LIMESTONES.

The farmer indirectly applies phosphate of lime to his land in the marls and lime he lays on often in such abundance.

It is probable that all living creatures require and contain in their bodies a certain quantity of phosphoric acid in the state of phosphate of lime. When these animals die this remains in, and is buried with, their bodies.

In all our marls, shell and coral sands, chalks, and limestones, the remains of animals abound. In living corals Silliman has found from one-eighth of a per cent. to nearly one per cent. of phosphate of lime, and some of our limestones, like those of Derby, Yorkshire, and Northumberland, being ancient coral reefs, must therefore contain a variable proportion of phosphate of lime. In chalk I have found about one-fourth, in mountain limestone one-seventh, and in shell sand one-third of a per cent. of phosphate of lime.

Suppose the burned lime we apply to the land to contain only half a pound of phosphate in every hundred pounds, a dose of two hundred bushels (27 to the ton) would contain about eighty-six pounds of phosphate of lime, or as much as is present in three bushels of bones.

But the proportion of phosphate in our limes varies very much, and is no doubt often greater than we have above supposed it to be. When the land is regularly limed, therefore, the farmer must unconsciously add regular supplies of phosphate of lime to it, and no doubt this ingredient must often enter as an element into the fertilizing action of lime and chalk, especially in those

* See the author's *Lectures on Agricultural Chemistry and Geology*. 2nd Edition, p..811.

parts of our island where the use of bones and other artificial manures has hitherto made little way.

The proportion of phosphate of lime found in some marls is greater than has hitherto been discovered in any of our regular beds of limestone. In some of the foreign marls of which the composition has been given in a previous chapter (p. 10) between two and three per cent. of phosphate of lime was detected, but in some of the green sand marls of the south of England it has lately been met with in much larger proportion.

The green sand formation which lies immediately below the chalk consists of three divisions—the upper green sand of about 100 feet thick, coloured generally by green grains, the gault clay 150 feet in thickness, and the lower green sand of 250 feet which is often ferruginous or cemented by iron. Beds of calcareous marl occur in both the upper and the lower of these sands, and it is in these marls that the large proportion of phosphates has been discovered.

We are indebted to Mr. Payne, Mr. Nesbit, and Mr. Way, for our knowledge of the existence and composition of these beds. The remarkable productiveness in corn, of some of the soils resting on or formed from the marls of the upper green sand had long been remarked, and circumstances had led Mr. Payne to suspect that they might contain a large proportion of phosphates. On analysing a sample of one of these marls Mr. Nesbit found 4½ per cent. of phosphate of lime, and his result has been confirmed by Mr. Way. An examination of various pits in the neighbourhood of Farnham, in Surrey, has also enabled the latter gentleman and Mr. Payne to discover that there occur both in the upper and lower green sand, as well as in the gault which lies between them, beds or layers from one to three inches in thickness which consist to the extent of one-half or more of organic remains from which 40 to 60 per cent. of bone earth may be extracted.

Not only does this interesting discovery account to a certain extent for the fertility of these green sand soils, and for the alleged failure of bones when applied to them, but the quantity of these fossils is so large and in some spots they are so easily extracted that hopes are entertained of their proving valuable sources of phosphate of lime for commercial purposes.

This is certainly a very important consideration. For although it should prove that little could be profitably extracted in England from these beds, yet in other parts of Europe where they occur—as in Hanover, in the neighbourhood of Göttingen—and where they are also full of similar organic remains it may be possible to mine for them with a profit and thus to obtain the means of benefitting the agriculture of the world.

Mr. Cooper, of Blyghburgh Lodge, near Wangford, has published the result of a comparative experiment made with dissolved bones and dissolved coprolites (containing the mineral phosphate above described) in growing turnips on land which had been manured with farm-yard manure on the clover stubble, previous to the wheat crop of 1846. In 1847 he sowed white loaf turnips on the 3rd July on three different parts of the same field and on the 24th of November gathered the following proportions of crop per imperial acre:—

	Cost. s.	Cost. d.	Produce. tons.	Produce. cwt.
Bone dust 4 bushels (184lbs,) at 3s.	12	0	14	14
Sulphuric acid 70lbs. at 1½d.	8	9		
Water 70lbs., and 9 bushels of burned earth	0	9		
	21	6		
Coprolite powder 3 cwt. at 3s.	9	0	14	8
Sulphuric acid 168 lbs. at 1½d.	14	0		
Labour and burnt earth	0	6		
	23	6		
No manure			5	15

It appears from this result that the dissolved copro-

lites at nearly the same expense will yield as good a crop of turnips as dissolved bones. To make the above experiment more satisfactory the proportion of phosphate of lime in the powdered coprolite ought also to have been determined by analysis.

SECTION XI.—INFLUENCE OF PREVIOUS LIMING ON THE APPARENT EFFECT OF BONES.

What has been stated in the previous section enables us to understand how a system of culture which robs the land of phosphate of lime may for a long time be persevered in without any addition of bones or even of rich farm-yard manure, provided lime or marl be added at regular intervals. It also prepares us to anticipate that the effect of similar applications of bones should sometimes be less discernable where lime has been previously applied.

I have already adverted to the extensive use, and to the remarkable effects produced by bones on the grass lands of Cheshire. This is explained by the fact that the dairy husbandry of that county has long been extracting this phosphate of lime from the soil and exporting it in the forms of milk and cheese. I have elsewhere estimated that each cow in this way takes from the soil every year as much of this phosphate as is contained in 84 pounds of bone-dust;* it is easy to conceive, therefore, how much of this material must yearly be removed from the county, and how exhausting upon the whole district this removal must have become after a long succession of years devoted to the same kind of husbandry conducted in the same manner. The application of bones, therefore, restores what the

* See my *Lectures on Agricultural Chemistry and Geology*. 2nd Edition, 791.

land has been gradually losing, and hence one important source at least of the good effects they have been found to produce.

But it has been observed that in Cheshire bones do not effect so remarkable an improvement upon land that has been previously limed, and the cause of this difference has naturally been asked.

The observations I have made in the present chapter, and especially in the preceding section, supply us with at least a probable cause.

In so far as the action of bones depends upon the lime they contain, an abundant and previous addition of lime will prevent that effect, and to this extent diminish their useful influence.

And in so far as it depends upon the phosphoric acid, which in Cheshire is probably very much the case, the presence of this acid in the lime laid on will further lessen the usually marked effect which is known to follow the addition of bones.

I have lately examined five soils from one of the best districts of Cheshire, and have found in them the several proportions of 1·25, 0·75, 1·09, 0·58, and 0·56 pounds of carbonate of lime in a hundred pounds of the dry soil. These quantities appear to be much smaller than a high state of fertility demands. The addition of bones, therefore, will benefit such a soil by the lime they convey to it, and in so far as this is the case, lime alone would do the same, and would consequently lessen the apparent effect of bones applied at a subsequent period.

It is interesting to find variations in the operation of the same manure in different localities thus easily accounted for, and difficulties disappearing from before the practical man when the lights of science are called in to his assistance.

SECTION XII.—CONCLUDING REMARKS.

I have in the preceding chapters considered the various practical and theoretical questions connected with the use of lime in agriculture which have either suggested themselves to my own mind or have been brought under my notice by the writings and observations of others. I have explained the composition of the various natural and artificial forms in which it is applied to the soil—the changes which quick lime undergoes by slaking and subsequent exposure to the air—the quantity in which it exists in the soil, and is usually added to it—the circumstances which affect these quantities, and when and how it ought to be applied. I next described the effects which lime in its various forms of quick lime, chalk, &c., produce upon the soil and the crops—and I have discussed at considerable length the theory of its action or the various causes to which these effects are to be ascribed. I then adverted briefly to the effects of lime upon animal and vegetable life in so far as the question is interesting to agriculture—and to complete my review of the whole subject, I have devoted the last two chapters to the use and action of lime in the state of sulphate of lime or gypsum, and of phosphate of lime as it exists in bones in the various forms in which they are now employed as a manure.

In discussing these various points, I have not succeeded perhaps in making every thing clear—in regard to some of them future observation and research may probably shew me to be in error—and some important topics I may, from want of information, have unintentionally passed by.

It is something, however, to have brought a subject up to the knowledge of the time in which one lives; and I think that in what I have above written I may, on the whole, fairly claim this merit in so far as regards *the use of lime in agriculture.*

APPENDIX.

While the preceding sheets were passing through the press, my attention has been drawn more particularly to several points connected with the use of lime, and some new results being obtained, I annex them in the form of an Appendix.

SECTION I.—COMPOSITION OF LIMES FROM COCKERMOUTH, BRAMPTON, KILNHEAD, AND CARLUKE.

1°. *Cockermouth, Brampton, and Kilnhead limes.*—The vale of Annandale and the central parts of Dumfriesshire have, until recently, been supplied with lime for agricultural purposes very sparingly. Besides being sold at a high price at the kilns, the cartage added enormously to the cost—twenty miles being a distance to which it was not unfrequently carried.

The lime kilns erected at Closeburn by the late Sir Charles Menteath, and those at Kilnhead and Blacketrig, near Annan, were the principal sources of supply for Annandale and the vale of the Nith; and at these kilns the lime was sold at from 10s. to 13s. per ton, generally 12s., the price of coals for firing being high.

The completion of the Caledonian Railway has not only opened up new sources of supply, but has placed within the reach of the Annandale farmers a means of fertility they never before possessed. By cheapening the price, the same effect, which in so many other cases is observed, has been produced; not only are larger applications of lime now being made than ever were

before, but much larger sums of money are now being expended by practical men in the purchase of this article than they ever heretofore thought of doing.

The principal competition, hitherto, has arisen from the introduction of lime from Cockermouth and Brampton in Cumberland—the former coming to Carlisle by the Whitehaven, the latter by the Newcastle line of railway. The Cockermouth lime, from the abundance of limestone and coal on the spot, is sold at the kiln at 4s. per ton; and, after travelling fifty miles by rail, can be delivered at Lockerby for 12s. a ton, the price formerly paid by the farmers at Kilnhead, from which they had it to cart so many miles. Farther up Annandale the boon is still greater, the saving amounting to as much as 20 or 30 miles of cartage; and when the rates on the railways, which are at present 2d. per ton per mile, shall have been reduced, the saving will be still greater.

The grass lands of Annandale are much benefited by lime. It is applied at present at the rate of 7 or 8 tons per imperial acre; and sometimes 10 tons, or 270 bushels, are laid upon land limed for the first time. In Cumberland as much as 12 tons an acre are in some places applied, and its good effects are visible for fifty years.

Under this state of things, it was natural that the Annandale farmers should be anxious to know the quality of the new varieties of lime offered to them, and to have this quality proved by analysis. Mr. Stewart of Hillside, therefore, near Lockerby, sent me samples of the three limes from Cockermouth, Brampton, and Kilnhead, respectively, for the purpose of having the Cumberland varieties both analysed, and compared at the same time with the composition of that of Kilnhead, the value of which, by long experience, was known all over the district. The three samples were sent to me in the burned or quick state—that of shells,—and in this state they were found to consist of—

	Cockermouth.	Brampton.	Kilnhead.
Lime - - -	89·93	89·92	88·85
Magnesia - - -	1·02	1·88	0·43
Sulphuric acid - -	0·22	0·30	0·30
Phosphoric acid - -	?	0·15	?
Alumina and oxide of iron -	1·23	1·84	1·98
Silica in the state of silicate	4·92	2·16	3·39
Carbonic acid and moisture	2·68	3·75	5·05
	100·	100·	100·

Calculated from the above, the unburned limestones should contain of—

	Cockermouth.	Brampton.	Kilnhead.
Carbonate of lime - -	94·86	94·71	95·89
Sulphate of lime - -	0·23	0·32	0·32
Carbonate of magnesia -	1·26	2·32	0·54
Alumina and oxide of iron -	0·73	1.03	1·20
Phosphate of lime - -	?	0·33	?
Silica - - -	2·92	1·29	2·05
	100·	100·	100·

These three limestones are all excellent, therefore, for agricultural purposes, and nearly in an equal degree. They contain little earthy matter, and only a small per-centage of magnesia,—the proportion of carbonate of lime in the unburned amounting to 95 per cent, and of caustic lime in the burned shells to nearly 90 per cent.

Another circumstance on which the agricultural value of a lime depends, besides its composition, is the state of minute division to which it falls, or the degree to which it swells out when it is slaked by means of water. This is estimated by taking equal bulks of the unslaked limes, and measuring their relative bulks again when they are completely fallen or slaked. Tested in this way, the three limes above described increased in bulk as follows. The

Cockermouth lime increased $2\frac{7}{8}$ times,
Brampton - - - $2\frac{3}{8}$ -
Kilnhead - - - $3\frac{1}{4}$ -

According to these results, they all swell very much, but that from Kilnhead the most. It should, therefore, go the farthest when spread as a top-dressing in the dry state. The differences above found, however, when tried on a comparatively small scale, may not be confirmed when tried in the large.

The three varieties of limestone are all of one geological age,—belonging to the carboniferous or mountain limestone formation,—have all nearly the same composition, all swell very much when slaked, and may therefore be bought or applied indifferently with equal advantage, in the same circumstances, and at the same prices.

2°. *Carluke lime.*—After the preceding analyses of the Dumfriesshire and Cumberland limes had been completed, I received from Mr. Hope Johnston, of Raehills, for the purpose of comparison with them, a sample of the lime quarried and burned at Carluke, in the centre of Lanarkshire. This being also on the line of the Caledonian Railway, is capable of coming in competition towards the south, and especially about Moffat and the higher part of Annandale generally, with the Dumfriesshire and Cumberland limes, which are already brought in large quantities into the district laid open to them by this railway from Carlisle. It was, therefore, desirable that an analysis should be made of this Carluke lime, for the purpose of comparing its agricultural value with those of the others.

The limestone of Carluke belongs to the same carboniferous limestone formation as those of Cockermouth, Brampton, Kilnhead, and Closeburn; but the sample sent to me in the burned state was much fuller of the traces of organic remains than any of the other limestones appeared to be. In conformity with what I have above stated, this would lead us to anticipate the presence of a larger proportion of phosphate, and probably also of salphate of lime.

When submitted to analysis it was found to consist of—

	Per cent.
Lime - - - - -	89·78
Sulphate of lime - - -	1·45
Phosphate of lime - - -	1·93 to 2·33
Magnesia - - - -	1·69
Alumina and oxides of iron - -	2·76
Silica in the state of silicate - -	0 70
Carbonic acid and moisture - -	1·69
	100·

In the following table its composition in the burned state is shown in comparison with that of the Cockermouth, Brampton, and Kilnhead limes.

	Cockermouth.	Brampton.	Kilnhead.	Carluke.
Lime - - -	89·77	89·53	88·64	89·78
Sulphate of lime (gypsum) -	0·38	0·51	0·51	1·45
Phosphate of lime - -	?	0·33	?	1·93 to 2·33
Magnesia - - -	1·02	1·88	0·43	1 69
Alumina and oxides of iron	1·23	1·84	1·98	2·76
Silica in the state of silicate	4·92	2·16	3·39	0·70
Carbonic acid and moisture	2·68	3·75	5·05	1·69
	100·	100·	100·	100·

Agriculturally considered, these limes are all excellent. There are, however, three points in regard to the Carluke lime which are not undeserving of attention. *First*, the larger per-centage of phosphate of lime, about *two* per cent, which it contains. A ton of this lime will, if this proportion be correct, convey to the soil upwards of 45 lbs. of phosphate, *equal to what is contained in a hundred weight of bones.*

Second, the proportion of sulphate of lime contained in this lime is about three times greater than in any of the others.

Third, the Carluke lime contains less silica than any of the others. Whether this is to be considered an

advantage or a disadvantage, depends upon certain points as yet undetermined, which I shall explain in a succeeding section of this appendix.

The composition of the Carluke limestone, calculated from that of the burned lime, is as follows:—

	Per cent.
Carbonate of lime - - - - -	93·91
Sulphate of lime (gypsum) - -	0·85
Phosphate of lime - - - -	1·14
Carbonate of magnesia - - -	2·06
Alumina and oxides of iron - -	1·63
Silica - - - - - -	0·41
	100·

And the following table shows its relation in this state to the limestones from the other localities mentioned:—

	Carluke.	Cockermouth.	Brampton.	Kilnhead.
Carbonate of lime -	93·91	94·86	94·71	95·89
Sulphate of lime - -	0·85	0·23	0·32	0·32
Phosphate of lime -	1·14 to 1·48	?	0·33	?
Carbonate of magnesia -	2·06	1·26	2·32	0·54
Alumina and oxide of iron	1·63	0·73	1·03	1·20
Silica - - -	0·41	2·92	1·29	2·05
	100·	100·	100·	100·

SECTION II.—ON THE PROPORTION OF SULPHURIC ACID OR GYPSUM CONTAINED IN BURNED AND UNBURNED LIMESTONES.

In the analyses contained in the preceding section I had caused my assistant, Mr. Townley, by whom the analyses were made, to determine the proportion of sulphuric acid or gypsum they severally contained,—an ingredient not hitherto sought for in our native limestones or burned limes.

The proportion found by him in the four burned limes was, per cent,—

	Cocker-mouth.	Bramp-ton.	Kiln-head.	Carluke.
Sulphuric acid - -	0·22	0·30	0·30	0·85
Or of gypsum (burned)	0·38	0·51	0·51	1·45

Every hundred pounds of the first three, therefore, contain about half a pound of gypsum, or a ton contains upwards of eleven pounds. Where 8 or 10 tons of lime are applied as a top-dressing to grass land, a considerable dressing (90 to 110 pounds per acre) of gypsum, also, will, when these limes are used, be laid on at the same time. Where the Carluke lime is used three times this quantity, or about 3 cwt. an acre, will be applied. If gypsum, then, as is believed by many, exercise any special action upon the soil or plant, the exercise of this action, along with that of the pure quicklime, is to a certain extent secured when a heavy common liming is laid upon the land. And where gypsum is found to produce no good effect when artificially applied, it may be owing either to the presence, naturally, of a sufficient quantity of this substance in the soil already, or to its having been added artificially in a state of unknown mixture with the lime, as well as with the other substances laid on from time to time to improve the fertility of the land.

In regard to the gypsum thus found in the burned or quick limes, it was a matter of doubt whether it existed naturally in the limestone rock itself, or had been produced during the burning, from the sulphur of the coal employed. I was unable to test this, as I had no samples of the original Cumberland and Dumfries-shire rocks from which the limes had been obtained. I therefore caused the sulphuric acid to be determined in two samples of limestone from the Upper Ludlow rocks of the Silurian formation, in three varieties of carboniferous limestones, and in two of magnesian limestone,

with the following results—the numbers under each representing the per centage of burned gypsum in each :—

Silurian limestones. North Wales. No. 1.	No. 2.	*Carboniferous limestones.* Hairlaw, E. Lothian.	Granton, Edinbro.	Binnie Crag, Linlithgow.	*Magnesian limestones.* Midridge, Durham. No. 1.	No. 2.
0·37	0·41	0·62	0·36	1·08	0·50	0·39

It appears, therefore, that gypsum, ready formed, does exist in notable proportion in our limestones, as well as our burned limes. This is what we should expect, when we consider that all animals contain sulphur, and that many of our limestones are rich in organic remains. The prevalence of pyrites in many of them also leads to the same conclusion, though, no doubt, the proportion of gypsum must vary very much. In some it may be less, while in others, it is probably much greater than has been found in those I have caused to be examined. The progress of our inquiries appears to show that much more minute analyses of all the substances that come into our hands must hereafter be made, if we are to be able either to understand or to explain their exact relations to the fertility of the soil, or to the growth of our cultivated crops.

SECTION III.—ON THE EFFECTS OF BURNING UPON LIMESTONE.

The concluding observation in the preceding section, in reference to more refined analyses, obtains support and confirmation from some observations I have been lately led to make in regard to the effect of burning upon limestones.

Two main effects—the one chemical and the other mechanical—have hitherto by myself and others been

supposed to comprise all the good results which follow from the burning of lime. A *chemical* change is produced by driving off the carbonic acid, and from that of carbonate bringing the lime into the caustic state. A *mechanical* change is effected when, by natural or artificial slaking, the limeshells are made to fall into a powder, extremely minute, and capable of being widely and thinly spread upon, or intimately mixed with, the soil.

But two other chemical effects are in reality brought about, which may not be without their influence in modifying the action of the burned lime when laid upon the land.

1°. *Sulphate of lime is produced.*—To this kind of change I have already briefly alluded in the preceding article. It appears, from what is there stated, that limestones contain naturally a certain proportion of gypsum; but if we consider that ashes—the ash of coal—which varies in quantity, also contains a notable proportion of gypsum, and that the sulphur of the coal, as it burns in the midst of the burning lime, cannot fail to unite, in part at least, with the lime, and to form an additional portion of gypsum, we shall see that the lime, as it comes from the kiln, must contain considerably more of this substance than was present in the limestone introduced into the kiln.

The quantity of sulphur in different coals is very different, and probably it exists in them in different states, so that the proportion of gypsum produced in the kiln during the burning of lime must vary with the nature of the coal employed. When it is impure and sulphury, a larger quantity of gypsum will be produced than when the coal is comparatively pure.

The limestones themselves also vary in the proportion of pyrites disseminated through them. During the burning, this pyrites parts with sulphur, and gives

rise to the production of gypsum; so that the gypsum produced will be affected by the proportion of pyrites in the limestone as well as by that in the coal.

Whatever weight we may attach to the presence or absence of this gypsum in the lime, it is of consequence to bear in mind, that changes fitted to produce it, actually take place in our ordinary lime-kilns when either coal or peat are employed in firing it.

2°. *Silicate of Lime is produced.*—When a piece of common limestone is put into diluted warm muriatic acid, it effervesces, and gradually dissolves and disappears more or less completely. The earthy and siliceous matters remain behind in a powdery state, and the filtered solution, upon careful examination, is found to contain little more than a trace of dissolved silica.

If burned lime be treated with acid in the same way, it dissolves more readily, and with little effervescence, because most of the carbonic acid has already been driven off by the heat of the kiln. But the solution, even after standing, retains a milky or opalescent appearance, passes often with extreme slowness through the filter, and the solution, when filtered, yields, on evaporation, a variable but almost always a distinctly sensible, and often a considerable quantity of gelatinous silica. It is silica in the same state which, floating in the unfiltered solution, gives it the opalescent appearance, and filling the pores of the filter when poured into it, prevents the liquid from passing rapidly through. The gelatinous and dissolved states of this silica indicate that in the burned lime it was in combination with a portion of the lime, forming a silicate of lime. And as this silicate does not exist in the natural limestone, it must have been produced in the kiln during the process of burning.

The mode of its formation is simple enough. Sand (siliceous sand) and lime readily melt together and

form a kind of glass, and common window-glass consists in large proportion of such a melted silicate of lime. In the kiln, the silica contained in the earthy matter of the limestone unites with a portion of the lime, as the latter parts with its carbonic acid; and, in the burned shells, the silicate of lime thus produced necessarily exists.

As the proportion of earthy matter in limestones varies very much, the proportion of silicate thus formed varies in an equal degree. In the three limes from Cumberland and Dumfriesshire, of which the analyses have been given above, the per-centage of silica found in this gelatinous state amounted respectively to—

Cockermouth.	Brampton.	Kilnhead.
4·92	2·16	3·39

and as the silicate from which it had been separated by the action of the acid must have contained at least 47 per cent. of lime,* the per-centage of *silicate of lime* in these three varieties, as they came from the kiln, must have been at least,—

Cockermouth.	Brampton.	Kilnhead.
7·23	3·17	4·98

And as the earthy matter of the limestone is diffused uniformly through the whole mass, the silicate thus formed is likely to be so also. When the lime slakes, therefore, and falls to an exceedingly minute powder, the intermingled silicate will do the same, and will thus come to be spread uniformly over, or intimately mingled with, the soil, and to be presented to the roots of plants in so finely divided a condition that they can readily act upon it.

It has been asserted by some, and taken for granted

* I assume it must have at least as much lime as common wollastonite, or table-spar, which consists of 47·46 of lime and 52·54 of silica. But formed as this is, in the presence of a large excess of lime, it probably contains much more.

by others, that the silicates of potash, soda, and lime are, in nature, an important food of plants, and that they alone are endowed with the peculiar virtue of strengthening the straw of our corn plants. I cannot venture to say that such opinions are untrue, but it has not yet been proved by analysis in the laboratory that straw is uniformly strong in proportion to the quantity of silica it contains. So far as analyses go, the balance of their evidence is unfavourable to this opinion. Nor has it been shown by satisfactory experiment in the field that the straw can be strengthened by the artificial application of silicates to the soil. Both of these points remain still to be proved, if they are to be received in the affirmative. It is, nevertheless, certain that plants do require silica in some form in which they can take it up, and it is, therefore, reasonable to believe that the presence of this minutely divided silicate of lime may in reality be an advantage to the quicklime in which it occurs, and may contribute in some degree to the good effects which such lime produces upon the soil.

It is an old observation in many localities, that an application of lime strengthens the straw; and, though it has not been satisfactorily shown that such stronger straw actually contains more silica, yet it may be that it does, and that the silicate of lime thus brought within reach of the roots of the young corn may have been the source from which the increase of silica has been derived. This opinion will no doubt be tested hereafter by conjoined experimental and analytical investigation; but, in the mean time, it may be held as *not improbable* that a part of the beneficial action of burned lime may be derived from the silicate of lime intermingled with it.

The peculiar silicate formed in this way is decomposed with great ease. Very diluted muriatic acid, and even vinegar, separates the lime almost entirely from the silica it contains. This easy decomposition is

favourable to its utility as a source of soluble silica in the soil, when the roots of plants come in contact with it.

A novel question here starts up in regard to the relative value of limestones, and one which rather strikes at the root of our received opinions upon this point. If the production of a silicate of lime in the kiln add to the value of the lime obtained, will it not be better when it contains 15 or 20 per cent. of such a silicate than when it contains only 5 or 10 per cent? In other words, is a limestone, as hitherto believed, really more valuable in all cases, the less siliceous or other earthy matter it contains? The more siliceous matter present in the rock, the more silicate will be produced during the burning; and, provided the lime afterwards slakes well, the more of this supposed valuable compound will be conveyed to the soil the impurer the limestone is.

This is a question which can only be solved by careful experiment. It presents, however, a field of inquiry quite new, and not unpromising in useful results. It suggests a new mode of accounting for the observed differences in the action of different limes upon the same soil, and of the same lime upon different soils. It points also to a new principle of selection, according to which we may choose this or that lime as best fitted for this or that soil. If peaty soils be really devoid of silica in a form to strengthen the straw—supposing it to do this—then we ought by all means to select a lime which, by burning, would produce and contain a large per-centage of this silicate of lime, and the converse for soils on which no such additional strength is wanted. But I do not dwell on these points, as the whole subject is at present hypothetical. The analyses and conjectural deductions I have presented serve their legitimate purpose if they lead to careful experiment, as I hope and believe they will.

In conclusion, therefore, I may state, as a summary of the most important beneficial effects as yet known to be produced by burning limestone in the kiln, that—

1°. The limestone is deprived of its carbonic acid, and brought into the caustic state.

2°. A variable proportion of gypsum is produced at the expense of the sulphur of the coal, or of the pyrites present in the limestone.

3°. That a quantity of silicate of lime is formed, the proportion of this compound being dependent upon that of the earthy or siliceous matter naturally present in the limestone, and in the coal.

4°. That when slaked, the burned lime falls into a powder much finer and more impalpable that any that could be formed by mechanical art.

SECTION IV.—ON THE EFFECTS OF LIME IN DIMINISHING THE APPARENT ACTION OF BONES.

The beneficial action of bones as an application to the grass lands of Cheshire is now a matter of general notoriety, and the practice followed in that county has been successfully imitated in many other parts of the country. Some spots, however, are met with, even in Cheshire, upon which bones produce no sensible effect, and others upon which the good done by them comes far short of the farmer's expectation. The causes or reasons of such differences it is not easy in most cases to discover, and they naturally puzzle and discourage the practical man.

During a recent visit to Cheshire, one of these apparent anomalies was brought under my notice, and I was asked to explain it. The previous application of lime diminishes the effect of bones subsequently applied—why do bones not produce so marked an improvement

when the land has been previously limed? I have already briefly considered this point in the body of this little work (p. 238,) but it will not be uninteresting to my readers if I here enter a little more into detail.

The above question may be answered superficially by saying, that inasmuch as the adding of lime improves the grass in a material degree, there does not remain so much for the bones to do; and that though, when subsequently added, they may greatly augment the produce and richness of the herbage, yet the visible change cannot be so great or striking as if the grass had been in a poorer condition when the bones were applied to it.

But such an answer as this, I think, if applicable to the case, would naturally occur to practical men themselves. I take the thing observed, therefore, to be— that when applied after lime, bones do not produce an *equal proportionate good* effect as they would have done if applied before it. From what cause can such a circumstance arise?

There are several considerations which may lead us to at least a tolerable guess at the truth.

1°. The effect of bones upon the land is due to the action, single or conjoined, of three different substances contained in them. These are the animal matter, the lime, and the phosphoric acid. Their good effects are the greatest where the soil and plant are in want of all three; they may do the least perceptible good where the soil is deficient in none or only in one of them.

The liming of the land cannot interfere with the action of the animal matter of the bones,—has it an influence upon the efficacy of the lime or the phosphoric acid?

Before we can answer this question, we must understand how these two substances act in, or are respectively required and in demand by, the soil. The peculiar dairy husbandry of this county, (Cheshire), long

and successfully prosecuted, must have drawn from the soil, as I have elsewhere explained,* a large quantity of phosphate of lime; and it might, therefore, be naturally supposed that the entire benefit derived from the mineral matter of bones, consisted in its supplying or restoring this phosphate which the husbandry of the district was constantly removing.

But lime is required in the soil and by the plant for various other purposes besides that of yielding phosphate of lime; and therefore any very marked effect produced by bones upon poor grass land may be partly due to the phosphate it brings into the land, and partly also to the single action of the lime it contains. In other words, bones may in certain cases perform the united functions of lime alone, and of lime in combination with phosphoric acid.

In certain cases, I say. Such a case would arise were the soil naturally very deficient in, and therefore likely to be very grateful for, an addition of lime. Are the soils of Cheshire generally in this condition? Are they poor in lime? And would bones benefit them by their lime alone, supposing them to contain no phosphoric acid at all?

Analysis alone could answer these questions. I therefore had recourse to its aid.

First.—Every one who has travelled through the red land of Lancashire and Chesire has remarked the numerous open pits which here and there occur in the fields, and from which, time out of mind, it has been the custom to dig marl for the purpose of being laid upon the land. To what ingredient does this marl owe its observed good effect? Is it rich in lime, and does it benefit the soil by adding this substance to it? If so,

* *Lectures on Agricultural Chemistry and Geology.* 2nd Edition, p. 791.

the probability is increased that part of the fertilising influence of bones is due to the same ingredient.

I procured samples of several varieties of marl, which in different neighbourhoods were reckoned of superior quality. Two of these were analysed, and were found to contain 2·48 and 8·77 per cent. of carbonate of lime respectively. These results showed that the marls differed very much in calcareous quality; and that the natural soils must be poor in lime indeed, if they proved gratefully remunerative for the application of a substance, on account of its calcarous matter, in which the proportion of this ingredient was so small.

Second.—I examined next the soils themselves. Five samples, taken from as many different farms on the estate of the Marquis of Westminster, were found to contain per cent. respectively, when dried at 212° Fah., of

	1st.	2nd.	3rd.	4th.	5th.
Carbonate of Lime	1·23	0·75	1·09	0·58	0·56

These results showed that though the quantity present in some soils was double of that contained in others yet that all were very poor in this important ingredient of a fertile soil, and that none of them were likely to fail in showing themselves grateful for any additions of lime that might be made to them.

I conclude, therefore, that a part of the good which is seen to follow the application of bones to the grass lands of Cheshire, arises from their supplying lime, in which the soils are poor; and that the previous application of lime lessens the apparent action of bones—among other reasons—because it renders unnecessary this portion of the duty they perform on unlimed land.

2°. Another consideration which bears upon this question is connected with the chemical composition of the lime usually applied in this county. All limestones contain a trace of phosphate of lime. We have seen in the first section of this Appendix that the proportion of

this ingredient sometimes exceeds 2 per cent (2·33) of the weight of the burned lime. If the lime used in Cheshire be naturally rich in this ingredient, it may supply so much of it to the land on which it is spread as materially to lessen the immediate necessity of phosphate of lime to the soil, and thus to take from the fertilising virtue of bones, when subsequently spread over its surface.

It became desirable, therefore, to ascertain the precise composition of the limestones used in the county of Chesire. I have as yet had the opportunity of minutely analysing only two of the limestones from this part of England, and these, though used I believe within the county, occurring beyond it on the borders of Denbigh, and on the property of Mr. Biddulph. These two consisted respectively of—

	No. I.	No. II.
Carbonate of Lime	83·58	69·07
Sulphate of Lime	0·37	0·41
Phosphate of Lime	0·14	0·12
Carbonate of Magnesia	0.66	1·47
Alumina and Oxides of Iron	2·67	5.24
Insoluble siliceous matter	12·73	23·69
	100·15	100·

These limestones, when burned, would contain in the hundred lbs. of quicklime, 0·226 and 0·17 lbs. of phosphate of lime respectively. Or, a ton of the former would contain 5 lbs., and of the latter nearly 4 lbs.—the quantities contained in about 12 and 10 lbs. of bone-dust. An application of four or five tons of lime would therefore mix with the soil as much phosphate as a bushel of bones; and though this is a comparatively small quantity, yet, if it be considered, on the one hand, to what a minute state of division it is reduced by the slaking of the lime, and, on the other, how long the larger pieces of bone, especially in some of the Cheshire soils, remain undissolved in the land, we shall not refuse to concede that even this small proportion of phosphate may produce a sensible effect on the apparent

richness of the herbage. Four bushels of bones, dissolved in or reduced by means of sulphuric acid, have been found to equal 16 or 20 bushels in the dry crushed state, and alone to raise an average crop of turnips. It is not unreasonable, therefore, to ascribe some sensible effect to the mineral phosphates of one bushel on a soil very poor in them, when they are reduced to a far finer state of division and intermixture with the soil than any ordinary means of ours can bring about.

Granting, or assuming this, then, we have another reason why the previous application of lime should diminish the apparent efficicacy of an after application of bones. We see, in fact, as a satisfactory explanation of the difficulty we have been considering;—

First. That in soils so poor in lime as those of Cheshire are, bones produce a good effect in virtue merely of the lime they contain, irrespective of their phosphoric acid; and that, as a previous liming performs this part or function beforehand, a subsequent application of bones cannot prove so sensibly beneficial.

Second. But the main virtue of bones, in so far as it depends upon their mineral matter, lies in the phosphate of lime they convey to the soil. But as lime, in the state in which it is applied to the land, also contains a sensible quantity of the same phosphate in a very minute state of division, it supplies to the soil, when added beforehand, a portion of that ingredient, on which the value of the mineral part of bones mainly depends. In this way also, therefore, it operates in diminishing the visible fertilising effect which bones laid on alone are fitted and are known to produce. And thus the matter seems to be satisfactorily explained,

I will only add, as practical deductions from the above, that Cheshire in general appears likely to pay a good return for an abundant liming, now rendered easy and economical by the opening of railways; and that, by this use of lime, the outlay of money for bones may be considerably curtailed, with equal advantage to the land.

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[*Continued*.

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